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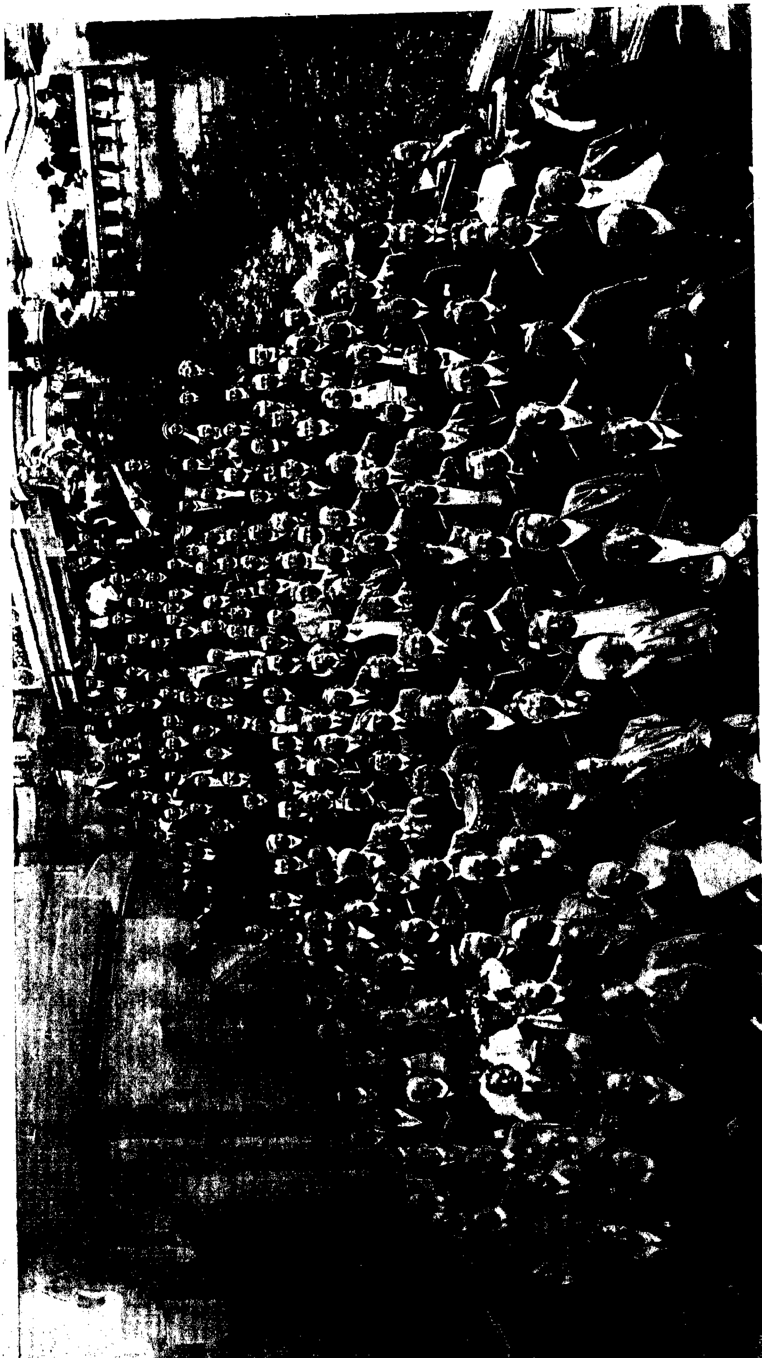

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TRANSACTIONS

OF

SECTION C

Electrochemistry

Honorary Chairman, PROF. DR. OSTWALD

Chairman, PROF. HENRY S. CARHART

Vice President, M. ALFRED DENNERY

Secretary, MR. CARL HERING

Assistant Secretary, MR. S. S. SADTLER

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Total number of papers present in Section C, 15.

Opening Session, Section C.

Monday, September 12, 1904.

Section C was called to order Monday morning, September 12, 1904, at 11:30 o'clock in one of the section halls of the Auditorium on Olive street, by the chairman, Prof. Henry S. Carhart.

The Chair announced that in the absence of the author, Dr. George W. Patterson, Jr., of the University of Michigan, would read the paper prepared by Prof. Theodore William Richards, of Harvard University, on "Compressible Atoms." Thereupon Dr. Patterson read the following paper:

THE RELATION OF THE HYPOTHESIS OF COMPRESSIBLE ATOMS TO ELECTROCHEMISTRY.

BY PROF. THEODORE WILLIAM RICHARDS, *Harvard University.*

The nature and origin of chemical affinity, and the laws which govern its irregular manifestation are veiled in unusual obscurity. There can be no doubt, however, that the chemical elements are in some way often firmly held together in compounds, and that in the process of forming these firm combinations much potential energy is usually converted into heat or electrical energy. The mechanism of this, the most important source of power to living beings, is hard to discover.

A few years ago, it occurred to the author that since affinity binds firmly, it should also exert pressure, and should therefore tend to combat all the influences existent in matter tending to distend the substance. The mutual affinity of two elements in a compound should, therefore, tend to diminish the volume of this compound; and, other things being equal, the greater the affinity, the greater would be the change of volume and the smaller would be the final volume of the resulting compound. If this relation really held true, it should be most clearly perceptible in compressible substances; hence a number of compounds of the easily compressible halogens, chlorine, bromine and iodine were studied with regard to this possible relationship. It was discovered that, in general, the volume of a solid chloride or bromide was much less than the sum of the volumes of the metal and the liquid chlorine or bromine entering into its composition; and, moreover, the more energetic the reaction, the greater was the change in volume during its progress.[1] That is to say, a great affinity evidently caused a great contraction. Subsequently it was found that this parallelism

1. Richards *Proc.* Am. Acad., Vols. 37, 38. *Zeitschr Phys. Chem.*, Vols. 40, 42

In this comparison the heat of reaction was taken as the measure of chemical energy. It was shown that where no great change of heat capacity occurs during the reaction this is a permissible proceeding — that is, under these conditions Berthelot's "rule of maximum work" holds nearly true.

of intensity of reaction and magnitude of contraction had already been noticed in some cases as long ago as 1881, by Muller-Erzbach, and later by Traube, and by Hagemann, all quite independently of one another.[2]

The relation, although in some cases quite striking, is in other cases concealed by other circumstances, especially by the differences in compressibility of various substances. It has recently been shown that, as one would expect, the more compressible the element, the greater the contraction which occurs for a given expenditure of energy.[3] The demonstration of this additional fact is a strong evidence that affinity really exerts pressure, and that the volume of a liquid or solid is dependent upon the intensity of this pressure. The attraction of cohesion also was shown to exert a similar effect When corrected for the compressibility of the factors in a reaction, and for the cohesion of both factors and products, the correspondence between the output of chemical energy and the change of volume during the reaction becomes so close as to leave little doubt as to the fundamental nature of the relation. In any attempt to penetrate further into the reason of these facts, some assumption, avowedly hypothetical, must be made concerning the ultimate nature of material. For the present purpose the atomic hypothesis furnishes the most convenient foundation.

The further question now presents itself:— What is that which is compressed by this pressure? In other words, what is the distending tendency in solids or liquids? Does the pressure of affinity simply restrict the vibrations of separate hard particles in an empty space, or is the atom itself compressible? It seems to me that the former usually accepted hypothesis does not sufficiently explain the difference between a solid and a gas. Moreover, even at the lowest attainable pressures, where the thermal vibration must be scarcely perceptible, ice occupies only about half the volume of the solid oxygen and hydrogen from which it may be made. Such a large change in volume seems incomprehensible, if it is imagined to be due to a restriction of thermal vibrations already almost infinitesimal. The undoubted variation of the quantity *b* in the equation of van der Waals, and many other facts, point in the same direction. In short, all that we really know of the volume of the atom must include the compressible environment which

2. Müller-Erzbach. *Berichte* d. d. Ch. G. *14*, 217, 2043 (1881). Traube. Raum der Atome (Stuttgart), 1899. Hagemann (privately published by Friedländer), 1900.

3. Richards. *Proc.* Am. Acad., *39*, 581 (1904).

seems always to surround it, for we have no direct means of knowing how that which we call material is distributed within this space — the imaginary, hard particle surrounded by an imaginary empty space is pure assumption. It seems to me, therefore, more rational to admit that the compressible environment is an essential part of the atom, or, in other words, that the atom itself is compressible. The other alternative, of imagining the atom to be incompressible, and the empty space alone to change in volume, has often been chosen simply because its mathematical handling is a simpler proposition; but ease of mathematical treatment is no evidence of verity in such a case. The need of an empty space for freedom of vibration in order to afford the chance of a mechanical explanation of heat in solids would at first seem to be an argument in favor of the separate hard particles, but it must be remembered that if the atom were elastic and compressible, its interior could vibrate even if its surface were bound. Hence this support also falls to the ground, and the theory of compressible atoms stands at least on the same level as its older brother, as far as probability is concerned.

It may be pointed out that the hypothesis of compressible atoms is entirely consistent with the corpuscular conception of atomic structure which is so popular today, or is equally consistent with an hypothesis which imagines all atoms to be built of the same continuous, compressible medium of which the corpuscles (if indeed they exist at all) are smaller aggregations.

The purpose of this paper is not, however, to discuss all the arguments which support the hypothesis of compressible atoms. Enough have now been brought forward to show that the hypothesis is a reasonable one, not to be cast aside without further thought. Whether or not it may be a nearer approach to a definite picture of reality is a question of less importance than that concerning its ability to suggest new experimental work, and thus to lead to new generalization based upon fact. Hypotheses are temporary in their very nature; it has been said that science is being built up of stones taken from their ruins. Perhaps it might rather be said that hypotheses are the scaffolding which the scientific man erects around the growing solid structure, enabling him to build more swiftly and freely. Danger can arise from the use of such temporary assistance only when the builder confounds the temporary with the permanent, and builds one into the other in such a way that the collapse of one injures the other; or when the scaffolding is so

badly constructed as not to bear a reasonable weight for a reasonable time.

The purpose of this paper is to show that this particular hypothesis, dealing as it does with very intimate relations of energy and material, is not without suggestiveness to the electrochemist, and hence also to the electrician.

Theoretical Electrochemistry may be divided into two closely related sections — that which treats of the phenomena at the electrode, and that which treats of the phenomena in the unchanged electrolyte. The former of these sections is the more important practically, and is likewise a more certain domain theoretically.

In the first place, then, one may ask:— How would a compressible atom behave on leaving an electrode and going into solution as an ion? It would then be attacked by an entirely new set of affinities, being in its new position surrounded by molecules of the solvent instead of by atoms similar to itself, and these new affinities exerting new intensity of pressure would be expected to change its volume. Moreover, the solvent, being itself in part exposed to new internal pressures, would also change in volume. As a matter of fact, a marked change of volume is always observed when a positive and negative element go into solution in the ionized condition. For example, a litre of a normal solution of potassic chloride occupies 43 millilitres less space than the solid potassium, liquid chlorine and water from which it may be made; the change of volume in the case of common salt is 31 millilitres, and that in the case of lithic chloride 17 millilitres. Potassic bromide in the same way gives a contraction of 33 millilitres. Among these similar compounds, and in many other cases, it usually appears that the greater the electrical potential afforded by the double ionization, the greater the change of volume; also, the greater the compressibility of the elements concerned, the greater the change in volume. It is worth while also to call attention to the fact that these changes of volume on ionization seem to be approximately parallel with the changes of volume on forming the corresponding hydroxides; just as the heats of ionization are approximately parallel with the heats of formation of the hydroxides. This parallelism may indicate that the effective agency causing ionization or galvanic solution of a metal is the attraction of the metal for the oxygen or the hydrogen of water — most probably the oxygen.[4]

Although these regularities are fairly prominent on comparing

4. Richards, *Proc. Am. Acad.*, 37, 13 (1901).

the properties of similar elements in a natural group, exceptions are not hard to find on comparing very dissimilar substances. Reason for these irregularities may partly be found in the extremely complex mathematical relations which must obtain if the atom is really compressible; but probably, at least, a part of the exceptions may be traced to the expected simultaneous contraction of the solvent already predicted. That the solvent really often contracts is manifest from the fact that in some cases (notably the hydroxides of lithium, sodium, and barium, and the sulphates of zinc, cobalt, nickel and magnesium) the solution occupies less space than the water alone, from which it is made.[5] In this connection it is worth while to call attention to the well known fact that during the formation of eighteen grams of water from its ions in the neutralization of a strong acid by a strong base, an increase of volume of 20 millilitres occurs — an increase greater than the volume of the water formed.[6]

Although by no means all possible cases can now be studied, because of lack of data, there is good reason to believe that in all cases both the solvent and the dissolved substances change in volume under the readjustment of internal pressures of ionization; and the resultant effect is so complicated that it is impossible, at present, except in the most exaggerated cases, to determine the mode of the distribution of the change.

Nevertheless, since changes of volume actually occur on ionization, and since in the more marked cases this volume-change seems to correspond roughly to the known compressibilities of the substances, and to the free-energy change during the reaction, the theory of compressible atoms is supported. At least, even supposing that the explanation herein given is rejected, the theory is here able to call attention to an interesting series of facts concerning volume-change, which must receive an explanation before a complete interpretation of the nature of a dissolved electrolyte is obtained.

Another less direct relation of the theory of compressible atoms to electrochemistry is to be found in the effect of change of volume of reacting systems upon their specific heat. Thomsen pointed out long ago that a contraction in a reaction between aqueous solutions is usually accompanied by a loss of heat-capacity of the

5. Thomsen, "Thermochemische Untersuchungen." I. 45 (1882). MacGregor *Trans.* Roy. Soc. Canada, 1890, Sec. III, p 19, 1891, Sec. III, p. 15; *Trans.* Nova Scotia Inst Nat. Sc., 7, 368 (1890).

6. Ostwald, "Volum-Chem Studien." *Pogg. Ann.* Erg. Bd, *8*, 154 (1876).

reacting system; and it is possible to cite many other cases in which this is true. Probably, however, the cause of this loss is not so much the decrease in volume, as the irregular stress caused by the simultaneous presence of very different affinities. In terms of the hypothesis of compressible atoms:—atomic distortion seems to cause a diminution of heat capacity. As a kinetic conception, this interpretation is plausible.

The relation of this change of heat capacity to electrochemistry is very important. Recent study has made it appear highly probable that a change in heat capacity during a reaction is the chief, if not the only, reason why the total-energy change (or the heat of the reaction) is not equal to the electrical work which the reaction performs in a galvanic cell.[7] In colloquial language, the heat energy which is displaced, or forced out, by a diminution of heat-capacity, does not seem to be able to perform work. If this be true, change of heat capacity is responsible for the "bound energy" of a galvanic cell, and, therefore, according to Helmholtz's equation, for its change of potential with the temperature. If, further, the preceding conclusion based upon the theory of compressible atoms be also accepted, the fundamental cause of this temperature coefficient of the electromotive force is referred back to atomic compression and distortion, which diminish the possibility of heat-vibration in the compressible atom.

One essential condition of ionization has not yet been dwelt upon; namely, the relation of ionization to the quantity-dimension of electricity. Recent investigation has shown that Faraday's law is not merely an approximation, but is rather one of the most exact of the laws of nature.[8] If the atomic theory be accepted, one must therefore admit that each similar atom, on ionizing into a liquid, receives or releases *exactly* the same charge, which is a precise, simple multiple of a given unit. What now does this unit of charge signify? In other words, what are the essential attributes of electrical quantity, and what explanation for this exact and fundamental law can be found in the theory of compressible atoms?

To the electrochemist who has nothing to do with electrical capacity, the quantity-dimension of electricity is important merely as a number. He recognizes it only because it is proportional to

7. Richards, *Proc.* Am. Acad. 38, 293 (1902). Van't Hoff, Drude's *Ann.* Boltzmann, Fest-Schrift, 233 (1904).

8. Richards and Heimrod, *Proc.* Am. Acad., 37, 415 (1902); Richards and Stull, *ibid.*, 38, 409 (1902).

equivalent weight of deposited metal, or to equivalent volume of evolved gas. Still more simply, it may be said to represent to him nothing but the number of atomic contacts which are made or broken in a given reaction. Therefore, the electrochemist, attempting to discover the relation of the compressible atom to galvanic deposition, naturally first seeks to imagine what would happen to a compressible atom on making or breaking a firmly united atomic contact with another atom.

Evidently, for each union with other atoms, a given atom would give and suffer a shock of impact or combination. The exact effect of this shock upon the atom itself cannot be determined; but if the atom is compressible throughout, many forms of vibration or temporary rhythmical distortion might be possible because of this shock. One of the most probable forms is perhaps a vortex motion; and it will be seen that this form lends itself best to further interpretation. If the internal substance of the atom were perfectly frictionless, such a vortex would continue to exist indefinitely, when once formed.

Let us imagine, then, that each collision of atomic combination starts or transfers a vortex or some other form of self-perpetuating shock.[9] Then the deposition of a given number of chemical equivalents will result in the transfer of a given number of shocks, or a given quantity of electricity, and Faraday's law is explained. In short, in order to conceive logically of this law, one need not ascribe weight or mass to the electron,—a permanent vortex will represent the needed unit as well as a ponderable particle. But only a compressible atom could hold or carry such an infinitesimal vortex, hence this hypothesis is dependent upon the hypothesis of compressible atoms.

This easy explanation of Faraday's law without a material conception of electricity leads one to inquire whether or not other relations of electricity might not likewise be satisfied by a vortical conception of the unit of electrical quantity. A complete study of the details of this possible explanation would be out of place, but a few of the electrical properties of substance may be mentioned

9. It is not important for this explanation that the disturbance should be precisely the wing-vortex usually meant by this word. Any kind of permanent twist or whirl might answer. No attempt is made in this paper to decide whether the difference between positive and negative consists simply in a respective deficiency and excess of these vortices, or in a difference between right and left-handed motion, which Professor A. E. Kennelly has suggested to me as possible.

in this connection. For example, the electrical conductivity of solids is in many cases what it would be expected to be, if their atoms were compressible. Atomic distortion would be expected to interfere with the ready transference of the vortices. The simpler the crystalline form, the less distorted would be the individual atoms, and the more easily would the vortices be received and transmitted from one atom to another. On the other hand, with irregular atoms, permanently distorted by chemical affinity, the uneven structure would receive and transmit the vortices less easily, and the potential energy of the mutual repulsion would be converted into heat. As a matter of fact, the two best electrical conductors among metals, silver and copper, crystallize in the regular system, and the poorest solid conductors among pure metals, bismuth, antimony and arsenic, are of less symmetrical crystalline structure. The non-metals which are all poor conductors, are still more noticeably complex in symmetry; and such non-conducting substances as bromine and iodine must be very much distorted in atomic shape, if their atoms are compressible, because these atoms must be much compressed on one side, by their firm union to form the diatomic molecules, and only slightly compressed on the other sides, by their feeble cohesion, indicated by great volatility. The relatively slight conductivity of alloys and compounds points in the same direction; for heterogeneity of atomic structure would imply irregular internal pressures, great atomic distortion, and hence poor conductivity. The considerable effect on conductivity of even slight impurity in a metal and the extremely low conductivity of substances like glass and cellulose are well known, and accord with this interpretation.

Again, it is easy to see how increased thermal energy, which, if atoms are compressible, must be supposed to exist as a simpler oscillation of a portion of the atomic centers, would interfere with the reception and transmission of this new vortex-motion, and hence to see why the conductivity of metals should decrease on raising the temperature. Moreover, one would expect the slightly distorted atoms, easily receiving the electrical vortex, should usually likewise transmit more rapidly the simpler oscillations of heat energy, which is a fact.

In applying the vortex idea to the statical and magnetic manifestations of electricity, one must imagine the vortex to cause stress in the surrounding wave-bearing medium, giving rise to the repulsion of similar vortices. Such a stress must be imagined whatever

conception one forms of the electron, and is at least as easily conceivable from a vortex as from a small particle of matter.

The explanation of the brilliant experiments of J. J. Thomson and his pupils on the basis of the vortical electron is possible, if one admits, as Thomson is quite willing to do, the existence of electrical inertia independent of gravitational effect. In this case, the cathode ray is to be considered as a collection of disembodied vortices, which may only be driven through the wave-bearing medium under the stress of great difference of potential. Another alternative must be adopted if one doubts the somewhat complicated evidence concerning the relative masses of the cathode-corpuscle and the atom, and believes the two to be identical. In this case it is necessary to imagine that a single atom can receive many vortices under the peculiar circumstances attending the cathode discharge.

Other possible relations of the hypothesis of compressible atoms to electrochemistry and to the new and surprising facts of radioactivity might be pointed out, but these examples will serve the present purpose. The object of this paper has been to show that the hypothesis is a suggestive one, because it views well known phenomena from a new standpoint, and therefore may excite the imagination into devising new methods of experimental attack. The discovery of the probable relation of the change of heat-capacity to the temperature coefficient of a galvanic cell is among the new relations to which this hypothesis has already led.

The long continued illusion of phlogiston, supported by eminent minds not much over a century ago, is enough to show the danger of a one-sided scientific consciousness, and the familiar conception of inflexible atoms may also to a less degree lead the literal mind into an intellectual rut. Of course no claim is made that the hypothesis of compressible atoms represents truly the actual fact; indeed atoms, in any shape, are an imaginary conception which may have no counterpart in reality. Even if the thinker progresses no farther than to admit that, provided atoms exist, they *may be* elastic and compressible, he has broadened the train of his thought and enlarged the realm of his imagination.

It has been claimed by a few that any hypothesis is harmful; but some of the most brilliant of scientific workers have used them as a continual inspiration. Faraday, one of the greatest of pioneers, dreamed thousands of such scientific day-dreams To him, these were nothing but a benefit; for although led on, by visions, he

knew well the difference between substance and shadow. He never confounded hypothesis with fact; and when new facts overthrew a favorite imagination, he would discard the latter gladly, rejoicing that it had led him to the discovery of new truth.

DISCUSSION.

The Chairman, Prof. H. S. CARHART: I would like, myself, to call attention to the long paragraph in the middle of page 12, in which the writer of the paper is discussing the question of compressibility and atomic distortion as the cause of the diminution of heat capacity, wherein he draws the inference that this diminution of heat capacity may account for the well-known fact that the total electrical energy, or the heat reaction, is not equal to the electrical work which the reaction performs in the galvanic cell; or, as I prefer to say, the voltaic cell. The author then proceeds to draw the conclusion that the heat which is thus forced out, or displaced, by this diminution of the heat capacity, does not seem to be able to perform work. That statement would appear to be purely hypothetical, as no reason whatever is given for such statement.

Further, if I understand the position of the author, his theory accounts for the difference between the total energy-change in such a reaction, and the energy given out in the electric circuit only when the temperature-coefficient is negative. You will observe that he says that this heat which is forced out by the compressibility or distortion of the atoms, is not able to perform work. It would, therefore, tend of course to heat, or raise the temperature of, the voltaic cell. This is consistent only with the case in which the temperature coefficient of the cell is negative, not positive. The temperature of a voltaic cell, of which the temperature coefficient is positive, falls when the cell furnishes a current. In that case, the energy given out electrically is in excess of the heat of reaction, and this is sufficient to account for the fall of temperature; but the author's theory would require atomic expansion and increase of heat capacity. So, if this hypothesis is to account for the temperature-coefficient of the voltaic cell on the basis of the author's statement, it will answer only for a negative temperature-coefficient, and not for a positive temperature-coefficient.

DOCTOR PATTERSON: Is it not possible that expansion may take place in these cells that are exceptions?

CHAIRMAN: The author does not call attention, I think, to any case of atomic expansion in voltaic cells, but only to contraction.

On motion, the Section then adjourned.

TUESDAY, SEPTEMBER 13.

Joint Session of Section C and the American Electrochemical Society.

In the absence of Chairman Carhart, Dr. Wilder D. Bancroft was appointed to the chair, and Mr. S. S. Sadtler to act as secretary.

The following paper was then read by the author:

ELECTRICAL EXTRACTION OF NITROGEN FROM THE AIR.

BY J. SIGFRID EDSTRÖM.

One of the most important minerals ever discovered is the Chile saltpeter. The saltpeter earth "Caliche" is found in northern Chile in layers of from a half to four meters deep. It contains between 15 to 65 per cent nitrate of soda ($NaNO_3$) and is changed in a number of factories in Chile into the so-called "raw saltpeter," which contains about 95 per cent nitrate of soda, and is shipped in this form all over the world. The Chile saltpeter is chiefly used for manufacturing nitric acid and fertilizers. In the year 1901 the consumption of Chile saltpeter in Germany alone was 500,000 tons. Of this quantity 75 per cent were used for fertilizers, 20 per cent for the manufacture of nitric acid, 3 per cent for the manufacture of nitrate of potash, and 2 per cent for the manufacture of sulphuric acid.

The demand for Chile saltpeter is increasing and the consumption growing heavier every year in spite of the rapidly rising prices. We may well ask if the saltpeter mines in Chile are inexhaustible. Several investigations have been made as to the extent of the saltpeter deposits in Chile, and the reports vary from 30 to 125,000,000 tons. We will probably come very close to the truth if we calculate that 100,000,000 tons still exist. When answering the question how long the deposit in Chile will continue to last, we must take into consideration two factors which primarily affect the life of the mines. First, the consumption, and second, the possibility of finding new saltpeter mines or means of manufacturing substances of equal qualities.

If we assume that the export of Chile saltpeter will develop at the same rate in the future as it has during the last 10 years, we can easily calculate how long the supply of the present mines will last. Fig. 1 shows graphically the report of Chile saltpeter during the years from 1830 to 1900. The export during the year 1900 was 1 1/3 million tons, and the yearly average increase during the last 10 years about 50,000 tons. Basing the future con-

sumption on the figures given above, the saltpeter mines would be exhausted somewhere about 1940.

Many efforts have been made to discover new deposits, but so far without success. Another way of counteracting the shortage of Chile saltpeter has been to substitute other chemicals, such as sulphate of ammonia for fertilizers, but this material is not to be had in sufficient quantities.

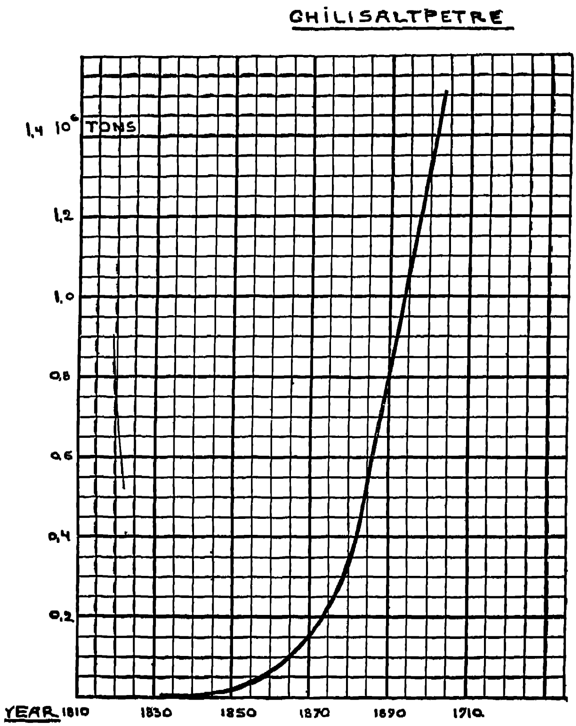

FIG. 1.

Some years ago experiments were made to produce the required nitrogen from the air by the application of bacteriology. The artificial production of an excess amount of bacteria in the earth and seeds tend to increase the power to absorb nitrogen from the air. The experiments have, however, not lead to any rational and economical application of this method.

Under these circumstances it is not to be wondered that in several ways other means of producing compounds of nitrogen have been sought. The nitrogen which is contained in the air

has been the source which has most naturally been turned to in seeking to produce a commercially useful article.

The Siemens & Halske Company, of Berlin, investigated a method invented by Dr. Frank for manufacturing cyanamide of calcium ($CaCN_2$). Originally carbide of calcium was heated and treated by a current of nitrogen. The nitrogen was received by carrying a current of air over glowing copper. The copper unites with the oxygen of the air and the nitrogen remains. Later, the same results were obtained by carrying the nitrogen over a heated mixture of chalk and carbon in the same proportion as used in making calcium-carbide.

The cyanamide of calcium has been tried as a fertilizer with good results. The method of Frank is as yet, however, only in its experimental state.

Most of the experiments for the manufacture of compounds of nitrogen are based on a compound with oxygen. Owing to the inert character of nitrogen it has been very difficult to bind and utilize the nitrogen of the air. As long ago as 100 years physical science knew, through the investigations of Priestley and Cavendish, that electric sparks through air caused the nitrogen and oxygen of the air to unite, and that nitric acid would be obtained as a product by this process. Toward the end of the last century this process was furthermore investigated by Wills, Plücker, Dewar, Lord Rayleigh and others, but it has been during the present century that investigations have pointed to a practical solution of the problem.

It was principally through the immense development of electricity that means have been provided for the solution of the problem. The first results from the experiments of oxidizing the nitrogen of the air were published by the Atmospheric Products Company, whose method was invented by Bradley and Lovejoy (*Electrical World and Engineer,* Aug. 2, 1902). The apparatus used in carrying out this method consisted chiefly of a solid drum or cylinder with a large number of platinum points placed inside the drum. Within the drum another cylinder is placed with points outwards. When the outer or inner drum is rotating the points come close to each other. The drums are connected to opposite sides of a high-tension direct-current system (8000 to 10,000 volts). When the distance between the points is small electric arcs are formed between the points. Through the motion of the drums

the arcs lengthen the break. At each arc under these circumstances naturally offers an exceedingly variable resistance, an inductive resistance is placed in series to regulate the current. Through the space between the two drums a current of air is sent, part of which is oxidized through the contact with the arcs. The fundamental idea of this invention is to obtain an electric arc of maximum length and minimum cross-section, in order to bring the largest possible volume of air into contact with the surface of the arcs. This determines the efficiency of the system, as the energy consumed in the arc is proportional to its volume It is evident that this effort of subdividing the arc results in a device in which the multitude of arcing points required for large capacities forms an objectionable feature in practical application.

The efficiency of the Bradley and Lovejoy system has been said to be one ton of 70 per cent nitric acid per kilowatt and year. This corresponds to about 700 kilogrammes hundred per cent HNO_3. Any further developments of this system have not been published, so far as I know.

Another method has been proposed by de Kowalski and M. Moscicki. According to the publication in the *Bulletin* of the Société Internationale des Electriciens, 3d June, 1903, his method consists of exposing the air to an oscillating electric arc with a pressure of 50,000 volts and a frequency of several thousand periods per second. The method uses the well-known combination of self-induction and capacity. Its efficiency is said to be one kilogram if HNO_3 per 15 kw-hours, which corresponds to 580 kilogrammes HNO_3 per kilowatt and year. Also in this method the amount of energy needs to be largely split up, thus complicating the apparatus in order to get good efficiency, when applying large amounts of energy.

A new method for the solution of the problem was invented about one year and a half ago by Prof. C. Birkeland and Mr. S. Eyde of Christiania. As far as now can be seen this method should give comparatively good results.

Prof. Birkeland and Mr. Eyde based their arrangements on the well-known fact that the electric current in the arc and with it the arc itself, can be deflected by a magnetic field, the deflection being at right angle to the lines of force.

Based on this fact, Prof. Birkeland and Mr. Eyde proposed a large number of arrangements, of which I will describe the one

which seems to give the best results. In Fig. 2 are shown two electrodes, E and E_1, which are connected to the poles of the electric generator G. The points of the electrodes are at such a distance that the pressure of the generator can maintain an arc between the electrodes. If a strong magnetic field is applied near the electrodes and at right angles to the direction of the electrodes, as shown in Fig. 2, the arc between the electrodes will momentarily be carried upward or downward, the direction of the current being for the moment from right to left or opposite.

For several reasons (one of which being the loss of pressure in the resistance L connected in the circuit) the pressure will fall between the electrodes at the moment the arc is formed.

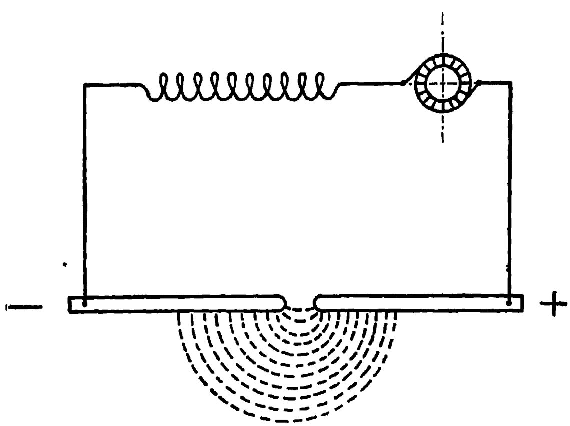

FIG. 2.

The arc will be carried outward by the magnetic field and grow longer as indicated by the dotted lines. Its resistance, consequently, rapidly increases until the pressure between the points is sufficiently high again to cause another arc between the electrodes. This arc having a lower pressure than the first one, the current will all pass through it, and the first one is extinguished. The speed of the arc is so rapid, however, and the formation of the new arc so instantaneous, that the arc can be formed several thousand times a second. In the practical form of the ovens only some hundred arcs per second are used. These arcs are formed, carried outward and extinguished so rapidly that to the eye they appear as a disc of arcs.

If the magnetic field is excited by a direct current, and the

generator delivers direct current for the arc, a continual series of arcs will be formed. These arcs move radially with a speed corresponding to the strength of the magnetic field. The striking points of the arc along the surface of the electrodes are also moving away from the points at the same speed. Thus the phenomena appear to the eye like a disc of arcs with the shape of almost a complete semi-circle. The movement of the arc near the electrodes is usually more rapid at the negative than at the positive electrodes, shifting the center of the circular disc somewhat to one side of a line joining the electrodes. If the magnetic field is excited by alternating current and the arc is fed by direct current, the arcs will vibrate between opposite sides of the elec-

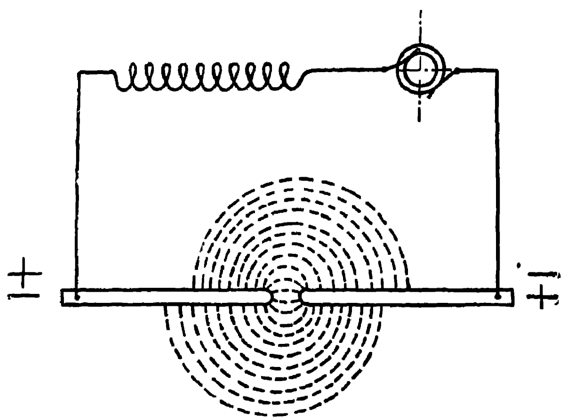

FIG. 3.

trodes. This will also be the case if the arc is fed by alternating current and the magnetic field by direct current, in which case the phenomena will appear as indicated in Fig. 3. It is principally this arrangement which has been used.

Fig. 4 shows the electric oven complete in a vertical section at right angles to the electrodes. The air that is to pass the oven is forced through the channels *A* and from them into the arc-chambers of the oven *B*, around and in the neighborhood of the electrodes *E*. Having passed this space from the center, and coming into the most intimate contact with the disc of arcs, the air passes out into the channel *C*, and leaves the oven mixed with a certain percentage of oxidized nitrogen.

If we look closer at this oven and the principles according to

which it works, we may easily discern the chief difference between this invention and the methods described before. The difference will be most strongly marked by quantitative results. While, with Bradley and Lovejoy and de Kowalski's methods, the energy in every arc must be lowered to the least possible in order to obtain an economical system, the method of Birkeland offers no objection to employing large amounts of energy in the disc of arcs. On the other hand experiments have proved that the economical efficiency increases with the amount of energy employed at the electrodes.

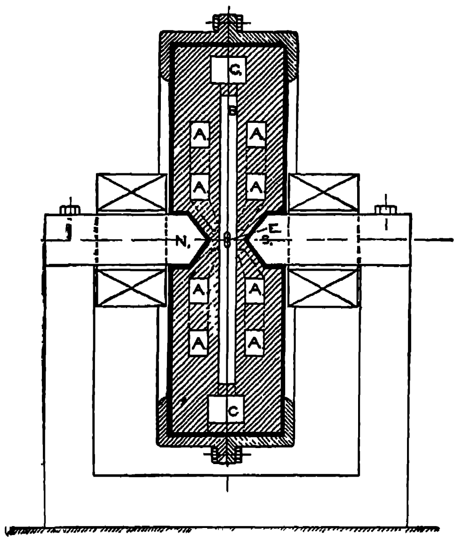

FIG. 4.

One of the ovens, which is still in operation, has consumed from 75 to 200 kilowatts in the disc of arcs between one single pair of electrodes, and lately an oven with a disc of arcs for 500 kilowatts has been built. The 200-kw oven has been fed with alternating current of 50 cycles frequency and 5000 volts pressure. From this will easily be seen that the amount of energy employed, and the class of current in the arc, can hardly be compared with the current that may be used by other methods.

In spite of the large amount of current the electrodes in Birkeland's oven have up to the present been used without interruption for several hundred hours. Owing to the fact that the striking points of the arc move along the electrodes, the destructive in-

fluence of the arc is inconsiderable. The electrodes can, for this reason, be made of very cheap material, such as copper or iron, and have such dimensions that they can easily be cooled by means of air or water, keeping their temperature within reasonable limits.

The oven of Birkeland and Eyde is consequently a very simple, strong and easily operated piece of apparatus, even when working with a large amount of energy. Electric current from any ordinary standard machinery can be used for its operation.

In the oven of Birkeland and Eyde, which was built about a year and a half ago, a small amount of energy was used in the disc of arcs only seven to ten kilowatts. The efficiency of this apparatus was at first only 400 kilogrammes HNO_3 per kilowatt and year. The next ovens were constructed for an increased consumption of energy and have now through continual improvements reached an efficiency of 900 kilogrammes HNO_3 per kilowatt and year. The energy referred to is the amount of energy in the disc of arcs itself.

This result has, of course, been gained after numerous difficulties and with many obstacles to overcome. I will not enter into the details of this work, but will only mention some of the factors that have been considered in connection with the improvement of the oven as follows:

The degree of moisture in the impressed air, its temperature, its amount of oxygen, its amount of air impressed per kw-hour, the different amounts of electric current used, the voltage of the electric current, the frequency, the ovens arranged in series and parallel electrically as well as with regard to the impressed gases, the strength of the magnetic field, the insulation of the oven to prevent the loss of heat, the introduction of various contact substances.

The air coming from the oven contains about 2 or 3 per cent of nitric oxide (NO). In order to be utilized it must be transformed into nitrogen peroxide (NO_2). This is done in a reaction tank of thin sheet iron enamelled on its inner side.

From the reaction tank the gases go through an exhauster of clay, where they come into contact with drips of thin nitric acid. From here the gases pass on through the absorption system, consisting of four towers for water and one tower for a solution of caustic soda. In each tower the fluid is sent through the tower several times. The strongest acid runs always through tower No. 1, where the gases first pass, the next strongest through tower No. 2,

and the weakest through tower No. 4. When the desired concentration is reached in tower No. 1 the acid is removed. The acid from tower No. 2 is then put into No. 1, from tower No. 3 into No. 2, from No. 4 into No. 3. Through tower No. 4 new water is passed. The process thus works according to the counter-current principle. The alkali tower contains, as previously noted, a solution of caustic soda. The gases from No. 4 pass through this tower. The remainder of the gases is absorbed here, and a mixture of nitrate and nitrite of soda is formed. From this pure nitrite of soda is manufactured.

The acid taken from tower No. 1 is either concentrated by use of Valentiner apparatus and shipped, or is turned into nitrate of calcium or nitrate of potassium (potash).

The Birkeland process has been put into actual operation, and compounds of nitrogen are being manufactured. It is to be hoped that the process will prove economical, and thus one of the greatest needs of the present time — cheap nitrogen in bound forms — will be introduced on the market.

The need of fertilizers is unlimited. Some years ago, when calcium-carbide was invented, numerous factories were built, and a great boom was given to the electrical industry. The market, however, proved too small, and the enterprise has languished. This can never occur with respect to the nitrogen industry, as the market is unlimited. Thus, if the industry is pushed forward, the electrical industry will benefit immensely. Moreover, all sources of energy will increase in value; waterfalls, situated in uninhabited parts of the earth, will be utilized, and great central stations in cities will, in many cases, obtain a profitable load now lacking. The immense waterpowers being all utilized, power will become cheap, which again will benefit industry in general.

Thus, if the process proves to be an economical success, the entire world of agriculture and industry will profit — and the process thereby will be a benefit to all mankind.

Discussion.

Prof. C. F. Burgess: These figures give 900 kilograms of nitric acid per kilowatt year, making it appear, therefore, that this is certainly a very valuable process. It appears that the efficiency is considerably higher than that claimed by the Niagara Falls process. But to interpret these figures correctly, the strength of the nitric acid should be given. I would like to hear what strength of nitric acid is to be obtained from this process.

MR. EDSTRÖM: It is 100 per cent nitric acid. One maker has attained a still higher efficiency, 950 kilograms per kilowatt-year, but I have given the intermediate figures.

PROFESSOR BURGESS: If the 900 kilograms represent 100 per cent nitric acid, that would mean, at the present market prices, something like $90 worth of acid for one kilowatt year, which would be a very profitable process if the power is the chief item which would have to be considered in the cost of operation.

MR. EDSTRÖM: Yes; but of course there would be many losses in the process. I have shown the amount of energy consumed, and all the other figures are based on that consumption; but there is a loss afterward, by leakage in the pipes, or in the coil.

PROFESSOR BURGESS. Then this figure does not include those losses?

MR. EDSTRÖM: It includes the energy in the arc itself.

DR E. F. ROEBER: I understand your arc moves in a plane. You light it by direct current and use a magnetic field, produced by a single phase alternating current, for deviating the arc. If, however, you excite the arc by direct current and use a revolving magnetic field (such as produced by the primary of an induction motor) to divert the arc, you would cause the plane in which the arc plays to revolve itself; you will no longer have a disc of arcs, but rather a globe of arcs, this means that a greater quantity of air would be acted upon by the arcs. Possibly this might increase the efficiency of the process. Did you make any experiments in this direction?

MR. EDSTRÖM: In reply to Doctor Roeber, I beg to say that, as far as I know, Professor Birkeland has not made any experiments in the line indicated. I think that the apparatus built on this principle would, however, be very difficult to design and construct. The ovens are very heavy, the latest one built weighing some seven tons. However, I will call Professor Birkeland's attention to the new idea brought forth by Doctor Roeber and thank him for the suggestion.

The following paper was then read by the author, who resigned the chair to Prof. C. F. Burgess:

THE CHEMISTRY OF ELECTROPLATING.

BY PROF WILDER D. BANCROFT, *Cornell University.*
Delegate of the American Electrochemical Society

Although some results have been obtained by Mylius, Foerster, Glaser, Burgess and others, a glance at the recent text-books on electrochemistry will show how far we still are from any consistent theory of electroplating. The reason for this is to be found in our neglect of the chemistry involved. The electric current is merely one agent for bringing about certain chemical reactions; but this is often overlooked and many of us consider a decomposition by means of electricity as much more mysterious than a decomposition by heat, for instance. I hope to show that a study of chemical reactions and chemical analogies will at least give us the outlines of a theory of electroplating.

When we speak of a good metallic deposit we may mean good from the point of view of the analyst, the refiner, or the plater. The analyst must have a deposit of pure metal in a weighable form but that is all. The refiner must have a coherent deposit of pure metal, except in the case of silver. Neither the analyst nor the refiner cares about the smoothness of the deposit, so long as no trees are formed. The plater must have an adherent smooth deposit which will burnish to an apparently amorphous surface. In the preliminary discussion we will rule out the plater and will call a deposit good when it is pure and coherent. Afterwards we can consider the further problem of the production of a very fine-grained deposit. Since there are very few data for anything except aqueous solutions, we will consider these only, though the general principles are equally applicable to all solvents.

When working with moderate current densities a bad deposit is practically always due to the precipitation of a non-metallic solid with the metal. When one of the single salts in the bath is sparingly soluble, as with the cyanides, this salt may precipitate. In most cases, however, the trouble is due to the presence in the deposit of oxygen either as oxide, hydroxide or basic salt. Whatever

will dissolve the salt readily under the conditions of the experiment will prevent its deposition, by definition, and should therefore improve the quality of the deposit. This has been recognized for zinc by Mylius and Fromm[1] and by Foerster and Gunther.[2] It has been put in a more general form by Glaser.[3]

I have made a list of the more important additions recommended in the refining, analysis, or plating of zinc, nickel, lead, tin, copper and silver. These are given in Table I.

TABLE I.

Zinc	*Tin*
Sulphuric acid	Sulphuric acid
Potash	Potash
Ammonium chloride	Sodium pyrophosphate
Ammonium sulphate	Potassium carbonate
Aluminum sulphate	Acid potassium tartrate
Potassium cyanide	Potassium cyanide
Acid potassium oxalate.	
Nickel	*Copper*
Sulphuric acid	Sulphuric acid
Ammonia	Ammonia
Ammonium salts	Alkaline tartrate
Potassium cyanide	Ammonium oxalate
Sodium bicarbonate	Potassium cyanide
Sodium bisulphite	Sodium bisulphite
Lead	*Silver*
Acetic acid	Nitric acid
Potash	Ammonia
Fluosilicic acid	Potassium cyanide
Sodium nitrate	Potassium iodide

All the substances under zinc dissolve zinc hydroxide. The first four under nickel dissolve nickel hydroxide; the sodium bicarbonate probably serves to keep the acidity constant; while the sodium bisulphite occurs only in solutions containing free ammonia. All the substances under lead dissolve lead hydroxide. Stannous and

1. *Zeit. Anorg. Chem.* 9, 144 (1895).
2. *Zeit. Elektrochemie,* 5, 16 (1898); 6, 301 (1899).
3. *Ibid.* 7, 365, 381 (1900).

stannic acids are soluble in sulphuric acid, in potash, and in a so-called sodium pyrophosphate solution; potassium carbonate is added only to neutralize an excess of free acid in stannous chloride solutions; while the cyanide and tartrate seem to be of very little value, unless perhaps at the anode. Under copper everything dissolves the hydroxide except sodium bisulphite and this is added to cyanide solutions to prevent loss of cyanogen when the copper changes from the cupric to the cuprous form. All four substances under silver dissolve freshly-precipitated oxide; in addition ammonia dissolves silver chloride while silver cyanide and silver iodide are soluble in potassium cyanide and potassium iodide respectively.

It is thus clear that there is a simple rational basis for many of the solutions in actual use. It must be kept in mind, however, that the rate of solution is more important than the actual solubility. Thus it is not easy to get a good deposit from an alkaline zincate solution at 20° whereas it is a comparatively simple thing to do this at 40° because the caustic soda reacts with zinc oxide or hydroxide much more rapidly at this temperature. It does not follow from this that a higher temperature would necessarily be even better. At 90° the action of caustic soda on metallic zinc becomes an important factor. With copper sulphate solutions rise of temperature means increased formation of cuprous sulphate and this must be taken into account. In each of these cases a study of the chemical reactions shows the cause of the difficulty.

While there is much evidence in favor of Glaser's first generalization, that a metallic deposit is improved by adding to the solution substances which will dissolve the oxide, hydroxide or basic salt, there are only a few scattered experiments which can be cited in favor of Glaser's second generalization that reducing agents improve the quality of the deposit. Glaser[4] observed that addition of pyrogallol or hydroquinone to a lead bath improved the deposit of electrolytic lead. Engels[5] states that the addition of hydroxylamine makes it possible to use higher current densities in the analysis of copper. It is believed that tin salts in solution improve the quality of a copper deposit[6] and it is known that ferrous salts are not disadvantageous. Good deposits of many metals are obtained from cyanide solutions and part of the effect, though certainly not the

4. *Zeit. Elektrochemie,* 7 381 (1900). *Cf.*, Elbs and Rixon. *Ibid.* 9, 267 (1903).

5. Smith. "*Electrochemical Analysis,*" 62.

6. Borchers. "*Elektrometallurgie,*" 193.

whole of it, may be due to the fact that potassium cyanide is a reducing agent. It is also possible that the merits of a tartrate solution may be due in part to the formation of reducing agents by oxidation at the anode.[7] In some experiments made at Cornell we have found that hydrazine improves the electrodeposition of cobalt and that resorcine has a slight favorable effect with zinc but apparently not with tin. The negative result in this last case may be due to the reducing power of the tin solutions. These instances will suffice to show that we do not yet know definitely how much influence a reducing agent has or how it varies with varying conditions. Since none of the reducing agents in question will reduce the oxide to metal, it seems very probable that the effect of the reducing agent may merely be to prevent oxidation by dissolved oxygen. If so, the effect should disappear in a vacuum or in an atmosphere of nitrogen. It has not yet been possible to try this experiment.

We have next to consider the effect of higher current densities. When solutions are not stirred we soon reach a point at which an ever-increasing current density causes a bad deposit. This change in the quality of the deposit is always accompanied by an increased evolution of hydrogen and it is usually believed that the evolution of the hydrogen is the cause of the deposit going bad. This cannot be the whole truth because hydrogen is evolved freely during electrolytic analyses and yet the deposit remains good. Further, the so-called critical current density varies enormously with the size, shape and distance apart of the electrodes, and also with the size and shape of the containing vessel, so that the data obtained by any one man usually cannot be duplicated by others. The most important factor is the rate of stirring. If we rotate a smooth copper, zinc or nickel cathode with sufficient speed it is by no means certain that there is any current density at which the deposit goes bad. With tin there does seem to be a limiting density but this is very possibly due to the formation of stannic salts in solution. It is intended to study this question in detail.

When a deposit becomes sandy or changes to a black powder, the polarization shows that there has always been the formation of a dilute solution at the cathode. In most cases this leads to the precipitation of an oxide or basic salt with the usual disastrous results.

7. Luther. *Zeit. Elektrochemie, 8,* 647 (1902); Schilow. *Zeit. Phys Chem. 42,* 646 (1903).

It is still an open question whether this is always the case. Foerster and Seidel[8] say that sandy deposits of copper are not due to the presence of oxide. If this statement is correct, we shall be forced to the assumption that the badness of the deposit is due to the pulsating or intermittent precipitation of hydrogen as a result of the intermittent formation of a surface film impoverished as to metal. This explanation does not appeal to me personally and I prefer to believe for the present in the oxide formation even if I have to account for the apparent absence of hydrogen by assuming a reduction to metal after the harm has been done.

Hydrogen may easily be indirectly the cause of a bad deposit. If hydrogen adheres as bubbles to the cathode, the deposition of the metal will become uneven and we shall have conditions favorable for treeing. A trouble of this sort can be cured chemically by adding an oxidizing agent to remove the hydrogen. It is known that copper solutions containing nitric acid will stand much higher current densities than will those acidified with sulphuric acid. It is clear that the prevention of hydrogen by means of an oxidizing agent may lead to the oxidation of the metal in which case we are out of the frying-pan into the fire. Foerster and Gunther[9] had difficulties with hydrogen bubbles during the precipitation of zinc. They show that such oxidizing agents as chlorine and ammonium persulphate prevent the appearance of hydrogen without causing the formation of zinc oxide. Such oxidizing agents as hydrogen peroxide and ammonium nitrate prevent hydrogen evolution but were worthless because they oxidized the zinc.

An oxidizing agent could probably be used to prevent occlusion of hydrogen by nickel, for instance. It is quite likely that the disadvantages would outweigh the advantages. In that case it would be better to approximate the same result by varying other conditions. The favorable conditions would be: a concentrated solution to ensure a good deposit; a high temperature to lower the obsorption coefficient; a nearly neutral solution to increase the decomposition voltage of hydrogen; and a high current density to give a fine-grained metal. For any given rate of stirring we should expect a limiting current density beyond which deterioration would occur. With increasing current density we get a finer deposit but there is also an increasing tendency to precipitate hydrogen and it is necessary to strike a balance between these two. All these conditions

8. *Zeit. Anorg. Chem. 14,* 125 (1897).
9. *Zeit. Elektrochemie, 5,* 22 (1898).

have been found experimentally for nickel by D. H. Browne[10] with the one exception that he finds a large addition of sodium chloride advantageous.[11] The reason for this is not clear.

Having considered the conditions for getting a good deposit from the refiner's point of view, we can now take up the question from the point of view of the plater. The problem is now as to the conditions under which the deposit is composed of very small, microscopic crystals.

When we precipitate a salt by chemical means we get larger crystals, the slower the precipitation and the higher the temperature. We should therefore expect that an electrolytic deposit will be coarser the lower the current density and the higher the temperature, provided all other conditions are held constant. The conclusion as to the current density is confirmed by all experiments. The case of the temperature change is a little more complicated because we may have hydrolysis and increasing acidity or alkalinity; we may have increased solvent action; and we may have a displacement of equilibrium as with copper sulphate. The effects due to these changes will of course superimpose themselves on the pure temperature effect and mask or even reverse it. In some experiments made in my laboratory Mr. Snowdon found that the deposit from an acidified copper sulphate solution became coarser as the temperature was raised from 20° to 40° and to 70°C. A similar result was obtained with a strongly acid zinc sulphate solution and with a lead bath. With nickel ammonium sulphate solution the effect of temperature on the crystalline structure of the deposit was too small to be detected. With a zinc sulphate solution which was only slightly acid, the deposit was more finely-grained at 40° than at 70°; but the deposit at 20° was coarser than either of the others. I suspect that at 20° the slight acidity had no appreciable effect on the deposit while it became an important factor at 40°. This hypothesis is confirmed by the other experiment in which a more acid solution behaved normally.

For a given current density, temperature and salt solution, we should expect a coarser-grained deposit the more concentrated the solution. This has been found to be the case in experiments with zinc sulphate and sodium zincate solutions. Since the potential difference between the metal and the solution is less the more con-

10. *Electrochemical Industry, 1*, 348 (1903).
11. Cf. Pfanhauser, *Zeit. Elektrochemie, 8*, 594 (1902).

centrated the solution, it seems probable that this is an important factor when we change from one solution to another. Other conditions being the same we shall get the smallest crystals, the greater the potential difference between the metal and the solution. This is the recognized explanation for the excellent character of the deposits from cyanide solutions.

A natural corollary from this last is that the deposit will be more finely crystalline, the greater the solvent action of the solution. This accounts for the small crystals that are obtained from an acid copper sulphate solution or from one containing nitric acid. This conclusion of course holds only within the limits for which we get a good deposit. The converse of this would be that reducing agents should increase the size of the crystals. Mr. Snowdon has found that addition of formaldehyde to a copper or a zinc solution does make the deposited metal more coarsely crystalline. Resorcine has a similar effect with zinc. It will be difficult to get conclusive evidence on this point because many reducing agents form complex salts and the effect due to this may easily overbalance the other. If the reducing agent acts only to remove dissolved gases, its effect on the size of the crystals would probably be negligible.

The addition of glue or similar substances to a solution tends to make precipitates come down in a colloidal form. Following out this analogy we should expect to find that addition of glue or similar substances to an electrolytic bath would decrease the size of the metal crystals, the limiting concentration being that at which the added substance causes a bad deposit owing to its chemical properties. It is known that the success of the Betts process for refining lead is due in part to the action of glue in preventing trees. We have found that the addition of ten grams of glue per liter of acidified copper sulphate solution improves the quality of the deposit from the plater's point of view.

One final point is of importance to the plater, the adhesion of the deposit. It has been suggested that an adherent plating deposit can be obtained only when the two metals can combine to form compounds or solid solutions.[12] This has also been denied.[13] While I have not yet made any experiments myself, I feel certain that Burgess is right and that this is purely a question of chemistry. The surface between two metals is a thin weld and it must show the

12. Kahlenberg. *Electrochemical Industry, 1,* 201 (1903).
13. Burgess. *Ibid.* 204.

same strength no matter how it has been made. In other words the adhesion of an ideally-made electrolytic deposit will approach that of a casting having the same size of crystals. Presence of grease, of air-bubbles, or of occluded mother liquor will impair the contact and weaken the joint. If the metal be deposited in a state of strain, the break will come at the weakest point. These are matters of general knowledge in making welds or castings and they are just as much first principles in electrolytic work. No one seems to have been struck by the absurdity of the statement, to be found in most books on plating, that nickel cannot be plated on nickel because it will not adhere. If this were true it would not be possible to deposit more than an infinitesimally thin film of nickel electrolytically. While it requires a higher voltage to deposit nickel than copper, nickel does not precipitate copper to any appreciable extent when immersed in a copper sulphate solution. The nickel becomes passive and is probably covered with a thin film of oxide. What people mean is that an "active" nickel containing hydrogen will not adhere to a "passive" nickel. There is nothing surprising or mysterious about this.

The alleged rusting of iron, when plated with nickel in a chloride instead of a sulphate solution, if really true, is purely a chemical phenomenon and rests on the different behavior of occluded chloride and sulphate solutions. If the distinction is a real one, special experiments would soon show whether the freedom from rust in sulphate solutions is due to the iron becoming passive or to the formation of an insoluble basic salt.

The general results of this paper are:

1. A bad deposit is always due to the precipitation with the metal of some salt or non-metal.

2. Addition to the solution of anything which will dissolve this salt or non-metal will tend to prevent its precipitation and to improve the quality of the deposit.

3. Any beneficial action of a reducing agent is probably due to the removal from the solution of dissolved oxygen.

4. A fine-grained deposit is favored by high current density and potential difference, by acidity and alkalinity, by low temperature, and by colloids.

5. Solutions containing oxidizing agents appear to yield small crystals while larger crystals are obtained from solutions containing reducing agents.

6. The adherence of deposits rests on the adhesion of the two metals.

The discussion has been incomplete. The formation of "trees" has only been touched upon and the question of "bright" deposits has not been raised. All of the generalizations rest on insufficient evidence. On the other hand, the consideration of the chemistry of electroplating has given us a working hypothesis which can be tested experimentally.

Discussion.

Mr. Edward F. Kerns presented the following communication on the subject from Prof. Anson G. Betts:

Professor Bancroft's paper, in my opinion, does not bring us any nearer a solution of the important question raised. It seems to me that there can be no scientific question concerning which it is more unsafe to build up theories without experimental verification of the data available. The reason for this is that experimental results and hypotheses are so conflicting.

I am not familiar with most of the references Professor Bancroft cites, but have repeated all the experiments in the articles by L. Glaser, which are referred to, and a great many others beside, in lead deposition. I have been entirely unable to verify this author's result claimed of a solid lead deposit.

I will give a few quotations from these articles, and think if Professor Bancroft had studied them he would not have based any theories on them.

"A solution of 40 grams of nitrate of lead and 10 grams $NaNO_3$ in 100 cu cm H_2O was treated under boiling with freshly precipitated hydroxide of lead. The solution, filtered while hot, still showed a slightly acid reaction. When cooling off, a part of the lead is again deposited as basic salt. A plain sponge formation is at once produced on the cathode. *It is thus proven that the solution has lost its property of depositing solid lead through treatment with hydrate.*"

Also he says, speaking of the first experiment he describes:

After the cathode lead had become about 2 mm thick, the plate was taken out and it was found that especially the upper part of the plate did not consist of pure lead, *but was intermixed with oxide although it was not yet possible to recognize a sponge formation.*"

His experiment 4 repeated with a current density of .6 ampere per sq. dm, gave a deposit consisting of a loose mass of crystals. In fact the deposits obtained by repeating these three experiments were practically the same in crystallization, the intermixed hydroxide exerting little or no influence on the structure of the lead crystals.

In repeating Glaser's experiments with the addition of ammonium persulphate to the electrolyte, which he recommends, I found that lead sulphate was formed on the cathodes, by the reaction between persulphuric acid and metallic lead. The white lead sulphate could be seen all through the deposit, but there was no difference in structure to be observed from

that obtained from the same solutions without the addition of the persulphate.

Professor Bancroft refers to "Glaser's second generalization that reducing agents improves the quality of the deposit." There is no such generalization to be found in these articles. The statement to which Professor Bancroft refers is probably the following:

"The addition of stuffs which can dissolve the basic salts, such as persulphate of ammonium in small quantities, likewise the development of hypochlorous acid in the bath, greatly increase the solidity of the precipitation. Additions of pyrogallol, hydrochinon, etc., have the same action." As persulphate of ammonium and hypochlorous acid are oxidizing agents, and hydrochinon and pyrogallol are reducing agents, it is difficult for me to see the derivation of the generalization.

Some of the general results of Professor Bancroft's paper are:

1. "A bad deposit is always due to the precipitation with the metal of some salt or nonmetal."

a). We have seen that the codeposition of lead hydrate and lead sulphate does not materially affect the character of a lead deposit, at least under some conditions, which are common enough.

b). Traces of cadmium added to a zinc sulphate solution cause a deposit of zinc which is perfectly solid and dense to immediately become spongy. Also lead electrolytes which contain considerable antimony and arsenic give a slimy deposit. In these cases we have the coprecipitation of neither a salt nor a nonmetal, but a foreign metal. The actual facts seem to me to be that the codeposition of some salt or nonmetal is detrimental merely to the extent that the foreign material occupies space that should be filled with metal, in order to get a solid deposit, but that the deposition of foreign metal particles, which will not alloy with the principal metal, at the moment of formation, is a very serious matter.

Result 2 is Result 1 stated conversely.

4. "A fine-grained deposit is favored by high curve density and potential difference, by acidity and alkalinity, by low temperatures and by colloids."

It was always my opinion that a low current-density rather favors a fine-grained deposit, and in the absence of any experimental data to prove the contrary, I do not see any reason why I am not as apt to be right as Professor Bancroft. With regard to temperature, it has been stated that with nickel at least a temperature of 70 deg. C. is better than a lower temperature. It may be that colloids are useful in improving the texture of a deposit, but I have made some attempts to get solid deposits with this means and been unable to.

5. "Solutions containing oxidizing agents appear to yield small crystals, while large crystals are obtained from solutions containing reducing agents." From a lead fluosilicate solution at least, in the absence of reducing agents, splendid large crystals are obtained, while with the addition of gelatine to the solution, the deposit is perfectly solid and noncrystalline.

I should like to suggest a few ideas on this subject. We can recognize two distinct causes for the failure of an electro-deposit. A deposit may either fail from being slimy, grading off into being soft, unsound and weak. I believe this is due to the codeposition of foreign *conducting* par-

ticles, in general caused by the presence in the solution of a small quantity of some metal of less chemical affinity than the metal being deposited. The foreign metal is precipitated in the minutest particles all over the surface, and if it comes down in too large quantity, or its affinity for the main metal is so weak that it is not immediately absorbed into an alloy, the same phenomenon takes place on an atomic scale that takes place on a visual scale when copper, for example, is being deposited and particles of slime are floating in the electrolyte. A particle of anode slime attaches itself to the cathode and very soon causes the formation of an insecurely attached lump of solid metal. The lumps are usually very easily knocked off and a particle of slime is almost invariably found underneath. A slimy metal must consist of such lumps on an infinitesimal scale.

The other cause of failure is the growth of a deposit toward the anode; the more elevated a particular point is from the cathode surface, the more rapid its growth.

Consider a rough electrodeposit as shown in section in the sketch. From the deposition of metal the solution near the cathode is lower in metal percentage than the main mass of the electrolyte, as is shown by the rising column of electrolyte at the cathode. In the cavities of the deposit this change of concentration has gone farther than on the point of a projection. We have in fact here a concentration cell, of which these two points are the electrodes and the cavity is immersed in a weaker solution than the projection. If there is no e.m.f. of this concentration cell, the deposit will grow equally, and the projections and cavities will be graudually smoothed out. If the concentration e.m.f. is in the usual direction, that is, the metal has a higher e.m.f. of solution in the weaker solution, metal will deposit faster on a projection than it will in a cavity, and we will have a "tree." If the e.m.f. is in the other direction, deposition will proceed faster in a cavity than on a projection, and the deposit will actually grow smooth, or if started on a smooth surface will remain absolutely smooth, and will have a polish. This result is rarely reached in practice, and the best we can usually do is to find a solution in which the e.m.f of the concentration cell is practically zero.

In depositing antimony from a solution of antimony trichloride, in which ferric chloride was continually generated in small quantities, I obtained a deposit that was as smooth and shiny as glass. In this case the ferric chloride in the solution performed the function of continually cutting off projections as fast as started. By the time the iron salt had reached an incipient cavity, it had passed and already reacted with the antimony of a neighboring projection, so that the rate of reaction was less the less the particular point was in the current of solution. The amount of ferric chloride used was from one-tenth to one-fifth the amount necessary to redissolve all the antimony deposited.

Dissolved oxygen in a bath would, no doubt, have the same function

were it not for the fact that the reaction between oxygen, an acid and a metal is infinitely slower than between ferric chloride and antimony.

In depositing silver from a nitrate solution, the deposit consists of more or less loose crystals, and projections are formed. From the cyanide solution the deposit is dense and solid. The reason appears to be that with the cyanide solution the e.m.f. of the minute concentration cells that must exist at the cathode is much smaller than with the nitrate solution.

In an acid copper-sulphate electrolyte we have present both cupric sulphate and cuprous sulphate. It is probable that in the cavities of the deposit more cuprous sulphate is present than near the projections, and it is also probable that the e.m.f. of solution of copper is less the more cuprous sulphate there is in the solution, which would account for the lower e.m.f. of the concentration cells and the solidity of the deposit.

In a lead fluosilicate electrolyte we have no monovalent lead ions corresponding to the cuprous ions of the copper sulphate solution.

I electrolyzed lead fluosilicate solutions with lead electrodes, with porous partitions to separate the anode and cathode compartments, so that I had a concentration cell, after some hours electrolysis, of which I could measure the e.m.f. The work was not done accurately, as I had no facilities for very delicate work, but I found in general that with gelatine present in the solution the e.m.f. of the concentration cells was from one-third to one-half as great as when no gelatine was present.

The same experiment repeated with the silver nitrate solution and silver cyanide solution, run in the same circuit, would be interesting. I should suggest that before reading the e.m.f. the current should be reversed for a very short time, so that electro-deposited metal will be present on both anode and cathode, so that the difference of e.m.f. of solution between cast metal and electro-deposited metal need not be considered.

In the dissolution of an anode we have the exact reverse of the conditions at the cathode. A solution which will give projections at the cathode, ought for the same reason to give pits in the anode. In the dissolution of a lead anode in a fluosilicate solution I have noticed that with gelatine present the surface of the lead underneath the anode slime remains much smoother than in the absence of gelatine. This fact would seem to prove that the cause of projections at a cathode is not to be sought in the chemical composition of the deposit, but in the physics of the solution.

With regard to the question raised by Professor Bancroft, whether a high or low current-density favors a fine-grained deposit, it would seem that if, with increasing current-density, the e.m.f. of the concentration cells increased more rapidly in proportion, then a low current-density would give a better deposit, while if this e.m.f. increases in less proportion a high current-density would be more favorable.

I hope that we can have some more experiments along these lines.

Prof. LOUIS KAHLENBERG: Where so many factors enter into a question as in this case, it is difficult to arrive at general conclusions; this is evident from the paper and also from the discussion so far as it has gone. I think it will be recognized that we have here touched upon one of the important questions of electrochemistry. It is evident that a vital point

in determining the physical character of an electrolytic deposit is the composition of the solution—the chemical make-up, if I may use the term, of the solution. Current-density, difference of potential, and temperature, all enter in as important factors to be sure; but if the chemical composition is not right, regulation of temperature, current-density, and e.m.f. will not give us the desired deposit. Attempts to get a dense smooth deposit of silver from an aqueous solution of silver nitrate do not succeed; the deposit is always crystalline no matter at what temperatures or current-densities the electrolysis proceeds. Neither does varying the strength of the solution or the e.m.f. result in producing a non-crystalline deposit. On the other hand, a silver nitrate solution in pyridine will always yield a dense, non-crystalline deposit. That increase in solubility improves the character of the deposit, as has been claimed, seems plausible from a number of cases. But it would be difficult to obtain a salt more soluble than silver nitrate in water, and yet, a smooth, non-crystalline deposit does not form when the aqueous solution of this salt is subjected to electrolysis. Furthermore, I am not pursuaded that it will be possible to maintain the general statement that high current-density and high potential difference always tend to yield a better deposit. Indeed it is well known that just the opposite has frequently been claimed as true. I believe the study of this question is not based upon a sufficient number of cases. We should not be too ready to draw general conclusions from a few isolated experiments.

It seems to me that Professor Bancroft has made a good beginning, but, as he himself admits, definite conclusions have not yet been obtained. Further work in this direction should be encouraged, and every one interested in electroplating ought to give it his careful consideration.

I am not at all sure what Professor Bancroft means by the term "soluble" as he uses it. Does he mean the amount of substance taken up by a given quantity of solvent, or the rate at which a substance dissolves? If the latter, this would depend, of course, upon temperature, surface exposed, stirring, as well as upon the nature of the substances concerned. It seems to me that this point should be carefully defined.

I may say, in regard to the matter of the adhesion of the electrolytic deposit as influenced by the affinity existing between the plating and the underlying metal, that the experiments of Roberts-Austen on lead and gold show conclusively that metals do penetrate into each other, in other words, that they do have affinity for each other, and that this is a factor which we can not ignore; although, as has been explained, changes of conditions, particularly those of temperature, may cause crystallization to set in resulting in disruption of the joint or union which under other conditions would remain quite secure.

Mr. Edw. F. Kern: If I am permitted, I would like to make a reference to a paragraph in a paper read by Mr. Anson G. Betts at the Albany meeting of the Mining Engineers in February, 1903, in regard to the smoothness of the cathode: "The smoothness and the purity of the deposited lead are proportional. Most of the impurity seems to be introduced mechanically through the attachment of floating particles of slime to irregularities on the cathodes. The effect of roughness is cumulative;

it is often observed that particles of slime attract an undue amount of current, resulting in the lumps seen on the cathodes. Samples taken at the same time showed from 1 to 2.5 oz. silver per ton in very rough cathodes, 0.25 oz. per ton as an average for smoother cathodes, and only 0.04 oz. in samples of cathodes selected for their smoothness."

I would also like to refer to the paper on "The Lead Voltameter," by Mr. Betts and Mr. Kern, in regard to the current-density and strength of solutions. This will be presented later, but it might be well to present this part now. By looking over the table you will see that the current-density used was from 7 to 37 amperes per square foot, and that the results are as accurate where large current-densities were used as with the smaller. We have here in one case employed a current-density of 37 amperes per square foot and in another 7.5 amperes per square foot. The smoothness of the deposit in both cases is about the same, irregardless whether a strong or weak electrolyte was used.

Now, in regard to the paper that has been read: Several years ago, while a student at the University of Pennsylvania, I carried out a research attempting to separate nickel and cobalt. This was done by converting the cobalt into potassium cobalti-cyanide similar to the formation of potassium ferri-cyanide in solution. The experiment I made did not come out as I expected, but I found that by the addition of potassium cyanide to an alkaline electrolyte of nickel, the deposit of nickel formed was smoother than that obtained by using other solutions. The addition of ammonium carbonate in place of ammonia produced smoother deposits when from 1 to 2 per cent of cyanide was present.

Prof. LOUIS KAHLENBERG: When nitrate of lead is dissolved in pyridine, you always get a smooth deposit of lead, although the salt is but sparingly soluble in that solvent.

Mr. EDW. F. KERN here exhibited a sample of lead, and said:

We have obtained lead an inch thick just as smooth as that. I only brought that because it is light.

Prof. C. F. BURGESS (in the chair): We ought to be thankful for a paper of this sort for our consideration. The electroplating industry is perhaps the oldest industrial application of our electrochemistry, but electrochemistry, at the present time, is in a most unsatisfactory condition as regards its literature. It has already been pointed out that when attempts are made to repeat experiments of others, in accordance with published directions, the result is frequently a failure. Especially is this true when good metal deposits are sought; but the failure to repeat the performances of others is due usually to incomplete description of all the conditions rather than to misrepresentation.

There are many varying factors that must be taken into account, and it is exceedingly difficult to classify them and tell what the variation of a single factor will produce in results. Doctor Bancroft has summarized in Table I the various materials which are employed in the production of good metal deposits, and he has thrown some light upon the reasons for using some of them. In regard to Doctor Bancroft's conclusions, I have no doubt that most of us who have studied the deposition of metals can recall instances which contradict his conclusions and cause us to differ

with him. But that is not necessarily criticism upon his paper, because most of the results will come under his scheme.

I would differ with the author in his statement on the first page that "neither the analyst nor the refiner cares about the smoothness of the deposit, so long as no trees are formed." As far as the refining is concerned, it is a preeminent requisite that the deposit shall be smooth. It must be smooth after the deposition has proceeded 24 hours, and after running 48 hours or even longer. Most electrolytic deposition for refining purposes requires 20 days, or more, which means that during the first few days, or even weeks, the depositions must be smooth, or otherwise you could never carry the depositions long enough to give a thick deposit. This difference of opinion is simply due to the difference in definition of what a bad deposit is. I would say, looking at it from the standpoint of the electrorefiner, that any deposit not laid down in a smooth layer is a bad one. Of course, from the electroplater's standpoint, a solution might give good deposition, while from the refiner's standpoint, it would give a bad deposition. Before attempting to classify the factors producing bad deposits it is necessary to define more clearly what bad deposits are.

Mr. Edw F. Kern: Referring to the sentence that "Neither the analyst nor the refiner cares about the smoothness of the deposit, so long as no trees are formed." The electrolytic lead refiner does care, for the smoothness of the deposit indicates the purity of the product. The smoother the deposit, the purer the product. In refining lead by the Betts process, you ought to get lead which will equal a purity of about 99.999 per cent. This you are able to get right along so long as you work to get smooth deposits, and we always work to that end and succeed in getting lead of the highest purity.

Prof. C. F. Burgess (in the chair): In Mr. Betts' discussion is pointed out the rather surprising fact that impurities collecting on the cathode serve to attract the current. This is surprising, since these impurities are usually non-conductors and would be expected to resist rather than facilitate the flow of current to those localities where they adhere. There is no doubt that such impurities become covered by a mound of metal, but it does not seem to me to be due to the attraction of the current, but rather to the high current-densities around the insulating material, and consequent coarse crystalline deposit which finally bridges over.

Mr. Edw. F. Kern: I would just like to mention that it seems to me that the particles of slime do not actually attract the current, but that they tend to conduct it. You get certain impurities, especially in lead refining, such as silver, antimony, bismuth and copper; these are in the slime as metals and conduct the current better than the lead, and probably this is one reason why the rougher deposits are less pure. The lumps indicating where particles of slime have attached themselves. Of course in copper refining you have sulphur in the slime, which acts as an insulator.

Dr. W. D. Bancroft: Mr. Betts says that the experiments of Glaser are not accurate and that he has not been able to duplicate them. Glaser's account of his own work reads like a straightforward statement of experimental results. In the absence of any evidence to the contrary I assumed

that he was describing what he found. If he was not, of course that part drops out, and I shall take pains to verify that. I do not really see the advantage in the quotation of some of the experiments giving the conditions under which Glaser did not get a good deposit, because these are not the subject of dispute at all. Then Mr. Betts states that Glaser does not make the generalization that a reducing agent improves the equality of the deposition. When I get back to Ithaca, I shall be happy to give the page reference.[1] In the case of cadmium and zinc, the deposition of small quantities of cadmium with the zinc is said to make the zinc deposit bad. Of course this statement postulates that the cadmium precipitates as metal. I am inclined to believe either that the cadmium precipitated as hydroxide or that the zinc and cadmium formed a local couple oxidizing the zinc. Instead of testing for hydroxide, Mr. Betts has preferred to ascribe a mysterious power to metallic cadmium. Mr. Betts objects to my statement that the addition of gelatine or glue improves the quality of the deposits, and says that his own experiments with lead show that he could not get a good deposit in that way. A little later on, in objecting to my statement as to reducing agents, he takes the opposite view. Mr. Betts apparently believes that glue has a good effect when added as a reducing agent and a bad one when added as a colloid.

Mr. Betts says that, in the absence of any experimental evidence, he thinks a low current-density gives small crystals. That would be all right if it were in the absence of experimental evidence. As far back as 1837, experiments were made by Golding-Bird in which a coarsely crystalline structure was obtained when a very low current-density was used. Similar experiments were made at a more recent date. As I stated in my paper, I have myself had a number of experiments made to test this particular matter, and we have some photo-micrographs showing the results. To draw accurate conclusions in regard to crystals, a microscopic examination should always be made.

The question of solubility, raised by Mr. Kahlenberg, seems to be based on a misunderstanding. I thought I was clear in what I said. I did not refer to the solubility of the metallic salt in the solvent. I spoke of adding something which would dissolve the oxide or hydroxide. This has nothing to do with the solubility of silver nitrate, for instance, in pyridine or water. As regards the rate of solution, the disturbing salt must dissolve faster than it precipitates, if one is to get good results The experiment cited by Mr. Kern of cyanide solution is covered by my paper. If we add potassium cyanide we increase the potential difference between the metal and the solution. Consequently, we get much finer deposits. It is generally known that most metals precipitate well from cyanide solutions. I refer to this specifically in my paper. As regards the other point that seems to be at issue, whether the refiner requires a smooth deposit in the sense that the plater does, I call your attention to the sample of lead which has been passed around. It is smooth from the point of view of the refiner, but I doubt whether any of you will call it smooth from the standpoint of the electroplater. You can take any copper cathode

[1] *Zeit. Elektrochemie,* 7, 386 (1900).

plate, and one which is smooth from the point of view of the refiner is a series of mountains from the point of view of the plater. Mr. Burgess says that every one of you can recall cases which contradict the rather crude outline which I have given. I shall be very much obliged, indeed, if those of you who do recall these cases will give me a memorandum of them at some time—either here or send it to Ithaca—for I should like very much to go over them to see whether they are really contradictions, or whether they are based merely upon a misunderstanding of the facts. There are a good many points in my article on which I do not care to lay much stress; but on the other hand, as you know, there have been no end of experiments in plating, and we are not very much further ahead than before. Now, if we can get anything which will give us a definite thing to test for, and can get further experiments in plating carried out in a rational way, and either prove or disprove something, it will not be long before we shall actually come out with a theory of plating which will be accurate, even in details.

The following paper was then read by Prof. C. F. Burgess, in the absence of the authors:

Prof. W. D. Bancroft in the chair.

THE CARBON CELL.

BY PROF. DR. F. HABER AND DR. L. BRUNER, *Technical High School, Carlsruhe, Baden.*

Among the various attempts to construct galvanic cells in which an electric current is produced by the consumption of carbon, there is none that has been of greater interest than the experiment of Jacques, who proposed the cell consisting of the following:

Carbon — fused sodium hydrate — iron.

This cell has been the subject of experiments by numerous investigators, especially Mr. C. J. Reed in America, and Messrs. Liebenow and Strasser in Germany. Experiments which we ourselves have conducted show that the true nature of this cell is different from what it was supposed to be.

Let us consider first the behavior of each of the electrodes separately.

The iron electrode in the fused sodium hydrate is gradually covered with a protecting layer or skin of the oxide. As soon as this has been produced, the iron is no longer attacked, whereas previously it went into solution in the fused salt as iron oxide, with the development of hydrogen gas. This protecting skin can be produced rapidly if the iron is dipped for a short time into fused saltpetre, and subsequently carefully freed from the saltpetre by means of water.

The iron thus coated with this protecting skin, is called "passive" because the fused sodium hydrate produces no further changes on it.

This passive iron represents an oxygen electrode on which the atmospheric oxygen acts similarly, but better, than on a platinized platinum electrode dipped into an aqueous conducting solution. This action of the oxygen is brought about by the presence of sodium manganate, which is always present in small quantities in fused commercial sodium hydrate, and especially when in contact with iron, and its presence can easily be proved chemically. Quite pure sodium hydrate, when fused and in contact with commercial

iron, will contain some manganese because a small quantity of manganese forms a normal part of commercial iron and gets into the fused salt when the iron is attacked by the sodium hydrate previously to the production of the passive state; by means of the atmospheric air it becomes a manganate.

The passive iron, as an unattackable electrode, can be replaced by another indifferent electrode, as for instance by platinum, without changing the force and the method of action of the electrode in fused sodium hydrate containing manganese.

If platinum is placed into pure sodium hydrate the potential at the electrode is uncertain. A very small quantity of a manganate suffices to give rise to a different value, which does not change during a further addition of a manganate up to 2 per cent of the weight of the sodium hydrate.

If the added sodium manganate is reduced by forcing in some hydrogen or carbon monoxide, or by the addition of sodium oxalate or sodium formate, quite an extraordinary change will take place in the potential. But by forcing in some atmospheric oxygen the original value of the potential is again reached.

In these experiments the potential of the platinum electrode is thus brought about by the absorption of oxygen. If a permanagate is added to fused sodium hydrate, oxygen will be evolved and the potential will, contrary to the other case, be brought about by the evolution of oxygen. These potentials are measured most simply by letting the syphon of a decinormal-electrode terminate in a small vessel containing concentrated sodium hydrate, which is in electric contact with the fused salt which is to be tested, by means of a rod of solid sodium hydrate. In all the measurements the fused salt was in a large silver crucible. The observed values for different temperatures are collected in the following table. The temperature was measured thermoelectrically.

Centigrade degrees	312	336	360	388	412	472	532
Potential in volts against decinormal-electrode	—0 265	—9 294	—0 314	—0.333	—0 353	—0.431	—0.472

These values were measured with a platinum electrode, a small quantity of the manganate being added to the sodium hydrate. Numerous tests showed that absolutely equal values of the potential are obtained with an electrode of passive iron. An earlier opinion from other sources, that the presence of certain steps in the oxida-

tion of the iron in the fused salt is of importance in the behavior of this electrode, is proved to be not correct.

Let us now consider the carbon electrode.

When a carbon electrode is tested in the way above described for iron and platinum, all possible values can be observed between — 0.6 and — 1.5 volts toward the decinormal-electrode. With closer study one finds that the potential approaches the value — 1.5 volts more and more, the more rapidly the carbon is attacked by the fused sodium hydrate with the evolution of gas. This attack is less the denser and the more graphitic the carbon is. Electrodes which are treated by the process of the International Acheson Graphite Company, therefore, remain very far from this value — 1.5 volts. Ordinary arc light carbons on the other hand can generally be made to produce a free gas evolution when the fused salt in which it is dipped is heated to above 500 deg. C. They then reach quite or nearly the value — 1.5 volts and remain at this value when the fused salt in which they are dipped is cooled to the point of solidification. But as the accompanying evolution of gas gradually diminished at a lower temperature (about 350 deg.), the potential will simultaneously change; it will diminish to the values — 1.3 or — 1.2 volts, etc.

The gas which the carbon electrode evolves in the hot fused sodium hydrate is hydrogen gas.

If, instead of the carbon electrode, a platinum tube is dipped into the fused sodium hydrate, and pure hydrogen gas is led through it into the liquid, one obtains with a strong current of gas the potential — 1.5 volts, and this will be the case at all temperatures between 500 deg. and the point of solidification of the fused salt. If the current of hydrogen gas is made weaker, the value — 1.5 volts will not be reached; the figures will be smaller. The potential of the carbon in the fused sodium hydrate is, according to this, not determined directly by the carbon, but by the hydrogen which the action of the carbon on the fused salt sets free. The temperature produces no effect on the potential within the given wide range, but the rapidity of the evolution of the hydrogen is of great importance.

Before we recognized this connection between the two, we had held a different conception concerning the process at the carbon electrode. We supposed that a formic acid salt or an oxalic acid salt, or carbon monoxide were produced, and that these materials

determined the potential at the carbon electrode. We, therefore, tested the action which an addition of the two named salts or the introduction of carbon monoxide had on the fused salt, and on the behavior of the platinum electrode which is dipped into the fused salt. We found by chemical investigations that former statements in the literature were confirmed, according to which oxalates and formates in an excess of fused sodium hydrate, pass over freely into carbonate and hydrogen gas. Formates may be assumed to be a combination of carbon monoxide with sodium hydrate, and oxalates may be assumed to be a combination of carbon monoxide with an alkali carbonate. We assumed, therefore, that carbon monoxide with sodium hydrate could also produce hydrogen and sodium carbonate. We found this to be definitely proved to be a fact, when we led carbon monoxide through a silver spiral heated to 350 deg., in which there was fused sodium hydrate. The following reaction is thereby obtained with great ease:

$$-CO + 2NaOH = CO_3Na_2 + H_2.$$

It can be proved by means of thermodynamics, that the oxalate, the formate and carbon monoxide, when they act as such on the electrode, should manifest their potentials, which exceed -1.5 volts. Such potentials, however, were never observed. On the other hand it was found that all three materials as such were inactive at the electrode, and that it was only the hydrogen evolved by them which charged them and brought their potential more or less closer to the value -1.5 volts, according to the rapidity of the release of the gas. According to these principles we are in a position to say that the so-called Jacques carbon cell is a hydrogen-oxygen chain, in which the oxygen of the air, by the intermediate action of the manganates at the iron electrode, acts with the hydrogen released by the carbon from the fused salt at the other electrode. The power of this element depends on the consistency of the carbon. If the latter is loose and capable of producing hydrogen gas evolution, one obtains those values which are found when one deducts -1.5 volts from the above-mentioned values for the oxygen electrode. As for instance $(-0.265 + 1.5)$ that is $+1.24$ volts at 312 deg. C, and $(-0.472 + 1.5)$ that is $+1.03$ volts at 532 deg. C.

Thermoelectric phenomena take no part in the production of these electromotive actions. For these forces do not depend in the least on the materials iron and carbon, but only on the gases

oxygen and hydrogen, and the same platinum tube shows alternately the force of the iron and the carbon electrode, if at constant temperature we pass through it oxygen and hydrogen respectively.

The element under discussion is without importance from the practical standpoint, because during its action the valuable carbon electrode and the equally expensive sodium hydrate are changed into cheap soda, only to obtain a little hydrogen which acts electromotively.

From the theoretical standpoint such a hydrogen-oxygen chain offers very much of importance. It is differentiated from the old well-known Grove hydrogen-oxygen chain, in that it is not liquid water, but a solution of water in fused sodium hydrate, which is produced by its action.

The relation which Helmoltz has proved for the connection between the electromotive force of reversible galvanic chains, and the reaction heat of the process which produces the current, enables us to calculate the heat of reaction in the present case. This is shown to be 81,650 gram calories per gram molecule of water produced. But as the formation of a gram molecule of water vapor at the range of temperatures of the experiment sets free approximately 58,650 gram calories, it follows that the evolution of heat which accompanies the absorption of a gram molecule of water vapor by a very large quantity of fused sodium hydrate has a value of approximately 23,000 gram calories. This high value arises from the fact that fused sodium hydrate holds the last traces of water with unusual tenacity, as has already been shown by others.

One can carry out the theoretical conception on the basis of the Helmholtz relation above given, in still another way. One can, for instance, suppose at the start that an equilibrium exists between a fused salt containing water, and the vapor pressure of the water above it. In this way one arrives at the conception that the action of our chain depends on the change of the atmospheric oxygen, which has a pressure of 0.2 atmosphere, and the hydrogen which has an atmospheric pressure, into water vapor of a pressure corresponding to the state of equilibrium above the water containing the fused salt. When we integrate the above-mentioned differential equation of Helmholtz, and for comparison consider the known values of the force of the Grove gas chain, we can calculate the vapor pressure above the fused sodium hydrate at different temperatures. The carrying out of these theoretical calculations re-

quires a more extended representation of the case and this departs too far from the intention of this discussion, to be embodied here. One can find it in an extended treatment of the subject which has appeared in the German language in the *Zeitschrift für Elektrochemie*.[1] The result of the calculations is that the vapor pressure above fused sodium hydrate at 300 deg. is extremely small and increases with increasing temperature. The fused mass is, therefore, especially hygroscopic near its point of solidification, and the force of the hydrogen-oxygen chain at this temperature is the highest. That the force of the Jacques carbon cell increases with the temperature is not in contradiction with this, but is explained according to our former statement by the fact that the evolution of hydrogen by the carbon increases in rapidity very quickly with increasing temperature.

Discussion.

The following communication by Mr. C. J. Reed, on the subject of the paper of Messrs. Haber and Bruner, was presented by Professor Burgess in Mr. Reed's absence:

I would call attention to the fact that the so-called Jacques cell was invented, not by Jacques, but by Henri Adolphe Archereau of Paris, who obtained for it British patent No. 1037, Feb. 26, 1883.

According to this paper the cathode of the cell consists of a film of iron oxide, which is not reduced by the electrolytic action but merely acts as an absorber of oxygen remaining itself unreduced. It would have added greatly to the interest of this paper if the authors had given some of the proofs of this statement, or at least indicated the nature of the experimental evidence on which the statement is based. Prof. Elihu Thomson[1] states as a result of his experiments that the action of the cell is to reduce this film of iron oxide to metal and the action of the injected oxygen is to reoxidize the reduced iron. All of my experiments have confirmed this. The film of oxide is always rapidly reduced on the passage of current to a film of metallic iron which has a characteristic grayish blue color and a powerful reducing action.

The statement in the paper that there is a permanent layer of iron oxide which acts as a cathode by absorbing and giving up oxygen, without itself undergoing electrochemical change, seems to me a most remarkable one and one that requires at least some proof. The authors do not even indicate the nature of the experimental evidence on this point if they have found any.

The paper states that this alleged peculiar behavior is brought about by the presence of sodium manganate, but does not state nor give us even a hint as to the manner in which the manganate accomplished this impor-

1. 1904, Vol. X, page 69F.

[1] *Jour.* Franklin Institute, Nov., 1896.

tant function, whether it is by chemical or electrochemical action or merely by its *presence*.

If the action of the manganate is merely by its "presence" and is not chemical or electrochemical, then the minute quantity of manganese said to be present, or even a single molecule, would be as amply sufficient as a larger quantity. But if the manganate has any chemical or electrochemical action, it is absurd to talk of manganate, in quantities so minute that, at most, only some thousandths of a milligram could be in contact with the cathode, transmitting currents of hundreds of amperes such as have been taken continuously for hours from these cells.

If (for the sake of argument only) we admit the allegations of the paper in regard to manganese and iron-oxide films, there is still no explanation on any theory except that of thermo-electric action, of the fact that an iron rod may be substituted for the carbon rod with the production of an even greater e.m f., amounting to as much as 1 15 volts.[2] Nor is there any explanation of the fact that a current of illuminating gas produces substantially the same effect as a current of air;[3] nor of the production of the current by the use of a crucible of pure silver instead of the iron pot and of sodium hydroxide made from metallic sodium free from manganese and all other impurities.[4]

The probable electrochemical reaction in the cell has been very clearly stated by Ostwald.[5]

He describes the reaction in the zinc-copper-oxide cell as the strict analogue of the Jacques cell, and the paper before us does not seem to me to contain anything which controverts the position taken by Ostwald. In order that there may be no misapprehension, and because Ostwald's statement is exceedingly clear, exact and positive, I will quote his words:

"We possess in this cell the complete analogue of the Jacques cell. The rôle of the zinc is played by carbon, the rôle of the oxide of copper by ferric oxide, or by sodium ferrate. The cell will work until one of the three necessary constituents is exhausted. Since, according to Jacques, ferric oxide is the constituent present in the smallest quantity, the activity of the cell depends entirely upon the renewal of the exhausted ferric oxide, i. e., on the amount of air or oxygen which is conveyed to the iron cathode.

"If we were to construct the Lalande cell with plates of porous metallic copper instead of copper oxide, we should then be able to obtain from it a current only in proportion as fresh copper oxide is generated, say by the blowing in of air to the cathode, or by allowing it to partially project in the air, and giving it a slow rotary movement, in such a manner that the reduced parts should be practically exposed to the air.

"As may be seen, in this cell as well as in the Jacques cell, the only active substance is the absorbed oxygen, and the energy which is set free by the union of the oxygen with the copper or the iron, is lost as far as the electrical process is concerned. There is practically no way known as

[2] *Electrical World*, July 25, 1896.
[3] *Trans.* Am. Inst. of Electrical Eng., Apr. 27, 1898.
[4] *Jour.* Franklin Inst., December, 1898.
[5] *Am. Electrician*, January, 1898.

yet for preventing this loss. If the cathode of the Jacques cell consisted of any nonoxidizable metal which would simply absorb the oxygen, as palladium absorbs hydrogen, a far higher e.m.f. might be secured, because in this case the potential of free oxygen of the air, which is very high, would become effective. Free oxygen, however, is unfortunately a substance which, despite its high potential, reacts very slowly, and in order to realize practical velocity of reaction, we must put up with the loss of potential resulting from the oxidation of copper or iron"

No theory could be more explicit as to the electrochemical reaction or harmonize better with observed facts than this statement of Ostwald.

The source of the e.m.f. is therefore a question of the energy of this electrochemical reaction. If the complete electrochemical reaction of the cell, including necessarily the chemical change at both electrodes, viz., the oxidation of the carbon and reduction of iron oxide, evolves energy, that energy will produce an e.m f. in the direction of the current. If this complete electrochemical action absorbs energy, it will oppose an e.m.f. to the current and the e.m.f. producing the current must necessarily originate in some other source than the electrochemical action.

The only possible electrochemical reaction, according to Ostwald's statement quoted above, is the reduction of an oxide of iron by the oxidation of carbon. Whether the carbon be oxidized to CO or CO_2 and whether the iron be reduced to the metallic state from an oxide, or reduced from a higher to a lower oxide, the energy of the carbon alone in either case is not sufficient for the reduction of the iron and can not, therefore, supply any excess in the form of electrical energy. There is only one other source of energy present, viz., the heat used in maintaining the high temperature. How can we escape from the conclusion that the heat is the source of the e.m.f. We must keep in mind that the energy of an equivalent carbon is less than the energy of an equivalent of iron and that an equivalent of iron can not be reduced by the energy of an equivalent of carbon, there being always required the energy of additional carbon burned in an additional independent reaction.

The thermo-chemical equations of the various possible reactions in this cell have been given by me elsewhere,[6] and if manganese were substituted for iron the electrochemical action would require even greater absorption of energy.

Measurements of potentials alone can not determine the electrochemical reaction of a cell. The measurements of temperatures and potentials given in this paper, however, show very clearly that the e.m.f. is not only dependent upon, but is directly proportional to, the temperature, as would be expected if the action were thermo-electric. The statement that "the temperature produces no effect on the potential within the given wide range" is a denial of the figures given in the paper, as well as a denial of our generally accepted conclusions thermodynamically deduced.

If I understand the authors correctly, the claim is that the e.m.f. of the cell originates in the union of free oxygen and free hydrogen and that the intensity of the e.m.f. is proportional to the rapidity with which the

[6] *Electrical World*, Jan. 2, 1897.

hydrogen is evolved and that this increases with the temperature. This is certainly a new theory of e.m.f.—that it is proportional to the quantity of the chemical reagent present.

I would ask where the hydrogen for this supposed reaction comes from? The paper says it is reduced by the carbon, but this can not occur without the absorption of heat, as will be seen by an inspection of the following thermochemical reaction:

$$\underbrace{C + H_2O}_{69} = \underbrace{CO + H_2}_{29}$$

$$\underbrace{C + 2H_2O}_{2 \times 69} = \underbrace{CO_2 + 2H_2}_{97}$$

The first reaction absorbs heat corresponding to $\frac{69 - 29}{2 \times 23.24} = 0.86$ volt, and the second to $\frac{2 \times 69 - 97}{4 \times 23.24} = 0.44$ volt. Where does this energy come from if not from the applied heat?

It seems to me there is a broad method of determining the source of e.m.f. in this cell, without reference to potential differences. If the energy of the current is derived from heat, the process must be thermo-electric. If it is derived directly from chemical energy, it is electrochemical or galvanic. The only possible source of chemical energy in the cell is admitted to be the oxidation of the carbon. If the carbon is directly oxidized by free oxygen, the process is combustion and produces only heat. In order to be electrochemical, the oxidation must be accomplished by oxygen derived from a preexisting oxide and by the decomposition of the electrolyte at both terminals, as in all other electrochemical reactions. Even in the Grove gas cell the oxygen and hydrogen must first combine with platinum before they can produce electrochemical reaction. With carbon electrodes, instead of platinum, the oxygen-hydrogen cell gives no e.m.f. and no electrochemical reaction. In the so called Jacques cell there is no oxide present which carbon can decompose without absorbing energy. The energy of combustion of the oxygen and reduced iron at the cathode, as Ostwald says in the passage quoted above, "is lost as far as the electrical process is concerned." As there is no possible electrochemical action present in the cell except those which absorb energy, the energy of the cell must be derived from heat.

Dr. W. D. Bancroft (Chairman): Experiments made in my laboratory several years ago showed that the carbon dissolved quantitatively, which does not seem quite compatible with very small reactions between oxygen and hydrogen; and further, I should think it might be interesting to learn what would happen in case the caustic soda were replaced more or less completely by sodium carbonate. Of course the temperature would be very much higher. Personally, I think the caustic soda is necessary for the reaction.

Doctor Kahlenberg: Do you say the carbon dissolves quantitatively or simply disintegrates?

Chairman: It dissolves very nearly quantitatively.

The following paper was then read by the author:

THE ELECTROCHEMICAL SERIES OF THE METALS.

BY PROF. LOUIS KAHLENBERG, *University of Wisconsin.*
Delegate of the American Electrochemical Society.

The current conception of the electrochemical series of the metals is the arrangement of the latter in a series so that any metal will be electropositive to all that follow it, and electronegative to all that precede it; and that any member of the series will chemically replace all the metals that follow it, and in turn be replaced by those that precede it in the series. In seeking combinations of metals that would produce the highest electromotive forces, Volta discovered the possibility of arranging metals in an electrochemical series; though, as pointed out by Ostwald in his history of electrochemistry, he did not at first realize that he had thus discovered a fundamental property of the metals.

Since the time of Volta the electrochemical series of the metals has figured with more or less prominence in all treatises on chemistry and electrochemistry. The position of the metals in the series is determined by their replacing power, but particularly by the difference of potential existing between the metals in contact with each other, or better in contact with an electrolyte. The electrolyte usually employed is a solution of some salt or acid in water. It has long been known that the character of the acid or salt and the strength of the solution used exert an influence upon the difference of potential between the metal and the solution. This point is well discussed by Jahn in the opening pages of his treatise on electrochemistry. Nevertheless, the general feeling with regard to the electrochemical series at present is that it really represents a fundamental property of the metals, and that, though the character of the electrolyte into which the metals are dipped when the electromotive forces are measured, affects the electrochemical series somewhat, such effects are but slight, and the order of the metals in the series remains essentially the same in all cases.

This view has no doubt been strengthened by the theory of Nernst, according to which each metal is endowed with an electrolytic solution tension, an inherent property of the metal tending to drive it into the solution into which the metal dips, and which varies only with the nature of the solvent employed in forming the solution. The theory of Nernst postulates the theory of electrolytic dissociation, and it is conceived that that which operates against the hypothetical solution tension of the metal is the so-called osmotic pressure of the simple ions of that particular metal in the solution. On the basis of this view, it would naturally be expected that the difference of potential between a metal and a solution of its salt would always be the same, no matter what other things might be contained in the solution or what solvent might be used, as long as the concentration of the ions of the particular metal in question remained constant. A few preliminary experiments made by Jones,[1] however, soon showed that it was necessary to assume that the electrolytic solution tension of a metal varies with the nature of the solvent.

During the last six years the differences of potential between metals and solutions, particularly such solutions in which water is not used as a solvent, have been one of the subjects of study in my laboratory.[2] In the course of these investigations, there were employed, besides carbon, twenty different metals as electrodes; thirty-five different solvents were used in making up the solutions; and fifteen different salts were employed as solutes. The metals serving as electrodes included all of those in common use, while the solvents and solutes selected represented, as far as possible, typical substances. In the selection of the solvents and solutes, the questions of securing sufficient solubility and electrolytic conductivity necessarily influenced the choice very greatly.

The outcome of all this work is the establishment of the fact that at a fixed temperature the difference of potential between a metal and an electrolyte depends upon the character of the metal and upon the composition of the electrolyte. Not only does the character of the solvent affect this difference of potential, or, if the theory of Nernst and the theory of electrolytic dissociation be assumed, not only does the osmotic pressure of the simple ions of

1. *Zeit. Physik. Chem.* 14, 346 (1894).
2. Compare *Jour. Phys. Chem.* 3, 379 (1899); Ibid., 4, 709 (1900); also *Trans.* Amer. Electrochem. Soc. 2, 89 (1902).

the metal in the solution and the so-called electrolytic solution tension of the metal determine the difference of potential, but *every* ingredient used in making up the solution affects this difference of potential to some extent, and frequently very materially indeed. Nor would the assumption of so-called complex ions, or of an influence which the solutes might have on the concentration of the ions of the metal in question (for which assumptions there would moreover frequently be no grounds) enable one to escape from the conclusion that the electrolytic solution tension of a metal is influenced not only by the solvent but also by the solute. But if the electrolytic solution tension of a metal is determined by the character of the solvent and also by that of the solute, it is plainly evident that this quantity, which is viewed by Nernst as an inherent property of the metal itself, is in reality as much a function of all the ingredients in the electrolyte as of the metal. In this connection it is of fundamental importance to bear in mind a further result of the investigations carried on here, namely, that the change which the difference of potential between a metal and the surrounding solution undergoes when any constituent of the solution is altered, is in general different, either as to magnitude or direction, or both, for different metals toward the same solution.

The facts established experimentally in these researches point to the conclusion that the difference of potential between a metal and an electrolyte into which the metal dips is due to the mutual chemical interaction of electrode and electrolyte. On the basis of this view the facts at hand can readily be explained. It becomes clear at once why a change in any ingredients of the electrolyte should affect the e.m.f. developed, and why in the case of different metals this effect should be different as to magnitude or sign, or both, for one and the same change in the electrolyte. At first thought it might seem that this view of ascribing the e.m.f. developed at the junction between a metal and an electrolyte to the chemical affinity, or strain tending toward interaction, existing between the metal and the electrolyte, would not enable one to detect regularities existing in the phenomena of the electromotive forces that have actually been measured, but this is a delusion. Similar metals behave similarly in the development of potential differences toward an electrolyte, and similar ingredients introduced into an electrolyte produce similar effects toward one and the same metal in the development of potential differences. Bearing this in mind

enables one to detect much of regularity in the electromotive forces measured.

As a striking instance of how the difference of potential between a metal and an electrolyte changes when one of the ingredients of the electrolyte is gradually altered, the following illustration may be given. The e.m.f. of the chain: Ag $\left|\frac{N}{10}\right.$ $AgNO_3$ in Pyridine $\left|\frac{N}{10}\right.$ $AgNO_3$ in Water|Ag, is 0.422 volts at 20° C., the silver in the aqueous solution being the positive pole of the combination. When in the first half of the chain pyridine is gradually replaced by water, keeping the solution one-tenth normal for $AgNO_3$ and allowing everything else in the chain to remain unchanged, the e.m.f. of the combination varies as indicated in Table 1. The first column shows the composition of the electrolyte of the first half of the chain by indicating the number of volumes of one-tenth normal $AgNO_3$ in water used to one volume of one-tenth normal $AgNO_3$ in pyridine; and the second column gives the e. m. f. found. The silver dipping in the one-tenth normal $AgNO_3$ solution in water remains the positive pole throughout.

TABLE 1.[3]

Volumes of water.	E M.F in volts.
0.00	0.422
0.33	0.376
1.	0.339
3.	0.300
7.	0.259
15.	0.210
32.	0.148
64.	0.055
127.	0.022
255.	0.013
511.	0.011

During the past year I have had Mr. J. P. Magnusson, fellow in chemistry at this university, measure the differences of potential between various metals dipping in a one-tenth normal solution of

3. This Table is taken from one of the papers cited above, *Jour. Phys. Chem.* 3, 279 (1899).

lithium chloride. The solvents used in making up these one-tenth normal lithium chloride solutions were pure pyridine, pure water, and mixtures of pyridine and water in various proportions. Great care was used to have all the materials employed of a high degree of purity, and to have the surfaces of the metals free from contamination. In each case the chain measured was of the form, Metal $| \frac{N}{10}$ LiCl in pyridine, water, or pyridine + water $| \frac{N}{10}$ $AgNO_3$ in pyridine | Ag. The second half of the chain always remained unchanged; and for the value of this half of the combination I had previously found[4]—0.573 volt,[5] on the assumption that the half cell, —nKCl·HgCl | Hg is equal to —0.56 volt.

In Tables 2 to 6, which follow, the metal in the first half of the chain is indicated in the first column; in the second column is given the total e.m.f. of the chain indicated at the head of the table; and in the third column is given the difference of potential of the first half of the combination referred to the value —0.56 volt for the normal calomel electrode. In computing the values in the third column, careful attention was paid to the sign.

TABLE 2.

Chain: Metal $| \frac{N}{10}$ LiCl in pyridine $| \frac{N}{10}$ $AgNO_3$ in pyridine | Ag.

Metal.	Total E.M.F.	E.M.F. of first half.
1 Mg	1.211 volts	+0.638 volts
2 Zn	1.043	+0.470
3 Cd	0.966	+0.393
4 Mn	0.808	+0.235
5 Al	0.705	+0.132
6 Pb	0.663	+0.090
7 Sn	0.618	+0.044
8 Cu	0.595	+0.022
9 Co	0.548	—0.025
10 Ni	0.444	—0.129
11 Sb	0.438	—0.135
12 Bi	0.423	—0.148
13 Hg	0.411	—0.162

4. *Jour. Phys. Chem.* 3, 379 (1899).
5. This value was fully confirmed by Mr. Magnusson.

TABLE 2 — (*Continued*).

Metal.	Total E.M.F.	E.M.F. of first half.
14 Ag	0.398	—0.175
15 Cr	0.387	—0.187
16 Au	0.309	—0.264
17 Fe	0.288	—0.285
18 Pd	0.251	—0.322
19 Pt	0.199	—0.374
20 C	0.154	—0.727

TABLE 3.

Chain: Metal $|\frac{N}{10}$ LiCl in 1 vol. water + 3 vols. pyridine | $AgNO_3$ in pyridine | Ag.

Metal.	Total E.M.F.	E.M.F. of first half.
1 Mg	1.697 volts	+1.124 volts
2 Zn	1.244	+0.671
3 Mn	1.069	+0.496
4 Al	0.895	+0.321
5 Pb	0.650	+0.077
6 Cd	0.637	+0.064
7 Cu	0.568	—0.005
8 Co	0.542	—0.031
9 Sn	0.486	—0.087
10 Fe	0.402	—0.171
11 Sb	0.384	—0.189
12 Ni	0.365	—0.208
13 Bi	0.365	—0.208
14 Hg	0.194	—0.379
15 Ag	0.169	—0.404
16 Pt	0.156	—0.417
17 Cr	0.125	—0.448
18 Pd	0.119	—0.454
19 An	0.101	—0.472
20 C	0.119	—0.692

TABLE 4.

Chain: Metal | $\frac{N}{10}$ LiCl in 1 vol. water + 1 vol. pyridine | $\frac{N}{10}$ $AgNO_3$ in pyridine|Ag.

Metal.	Total E.M.F.	E.M.F. of first half.
1 Mg	1.669 volts	+1.096 volts
2 Zn	1.247	+0.674
3 Mn	1.128	+0.555
4 Al	0.855	+0.281
5 Pb	0.698	+0.125
6 Cd	0.659	+0.086
7 Co	0.559	—0.014
8 Cu	0.528	—0.045
9 Sn	0.449	—0.124
10 Fe	0.411	—0.162
11 Sb	0.370	—0.203
12 Ni	0.336	—0.237
13 Bi	0.318	—0.255
14 Hg	0.106	—0.467
15 Cr	0.106	—0.467
16 Pt	0.074	—0.499
17 Ag	0.067	—0.506
18 An	0.006	—0.567
19 Pd	0.012	—0.585
20 C	0.121	—0.694

TABLE 5.

Chain: Metal | $\frac{N}{10}$ LiCl in 3 vols. water + 1 vol. pyridine | $\frac{N}{10}$ $AgNO_3$ in pyridine | Ag.

Metal.	Total E.M.F.	E.M.F. of first half.
1 Mg	1.662 volts	+1.089 volts
2 Mn	1.212	+0.639
3 Zn	1.188	+0.615
4 Al	0.828	+0.255
5 Cd	0.746	+0.173
6 Pb	0.669	+0.096
7 Co	0.548	+0.025
8 Cu	0.485	—0.088
9 Sn	0.436	—0.137

TABLE 5 — (*Continued*).

Metal.	Total E.M.F.	E.M.F. of first half.
10 Fe	0.417	—0.156
11 Sb	0.316	—0.257
12 Ni	0.316	—0.257
13 Bi	0.297	—0.276
14 Cr	0.082	—0.491
15 Ag	0.075	—0.498
16 Hg	0.056	—0.517
17 Pt	0.006	—0.567
18 Pd	0.006	—0.567
19 Au	0.015	—0.588
20 C	0.075	—0.648

TABLE 6.

Chain: Metal | $\frac{N}{10}$ LiCl in water | $\frac{N}{10}$ $AgNO_3$ in pyridine | Ag.

Metal.	Total E.M.F.	E.M.F. of first half.
1 Mg	1.666 volts	+1.093 volts
2 Mn	1.151	+0.579
3 Zn	1.111	+0.538
4 Cd	0.782	+0.209
5 Al	0.777	+0.204
6 Pb	0.697	+0.124
7 Fe	0.593	+0.020
8 Co	0.450	—0.123
9 Sn	0.403	—0.170
10 Bi	0.273	—0.300
11 Sb	0.271	—0.302
12 Cu	0.228	—0.345
13 Ni	0.189	—0.384
14 Ag	0.131	—0.442
15 Cr	0.065	—0.508
16 Pd	0.009	—0.564
17 Hg	0.020	—0.593
18 Pt	0.038	—0.611
19 Au	0.054	—0.627
20 C	0.067	—0.640

To facilitate comparison, the values in the third columns o Tables 2 to 6 are gathered together in Table 7, the headings of th columns of the latter table indicating the composition of the solven used.

TABLE 7.

The electrolyte was $\frac{N}{10}$ Li Cl, the solvent used being indicated by the heading of each column.

Pyridine	1 vol water plus 3 vols pyridine	1 vol. water plus 1 vol pyridine	3 vols water plus 1 vol pyridine	Water
Mg +0 638	Mg +1 124	Mg +1 096	Mg +1 089	Mg +1.093
Zn +0 470	Zn +0 671	Zn +0 674	Mn +0 639	Mn +0.579
Cd +0.393	Mn +0 496	Mn +0 555	Zn +0 615	Zn +0 538
Mn +0 235	Al +0.321	Al +0 281	Al +0 255	Cd +0.209
Al +0.132	Pb +0 077	Pb +0 125	Cd +0.173	Al +0 204
Pb +0 090	Cd +0 064	Cd +0 086	Pb +0 096	Pb +0 124
Sn +0.044	Cu —0 005	Co —0 014	Co —0 025	Fe —0 020
Cu +0 022	Co —0 031	Cu —0 045	Cu —0.088	Co —0 123
Co —0.025	Sn —0.087	Sn —0 124	Sn —0 137	Sn —0.170
Ni —0 129	Fe —0 171	Fe —0 162	Fe —0 156	Bi —0 300
Sb —0 135	Sb —0.189	Sb —0.203	Sb —0 257	Sb —0 302
Bi —0.148	Ni —0.208	Ni —0 237	Ni —0 257	Cu —0 345
Hg —0 662	Bi —0 208	Bi —0 255	Bi —0 276	Ni —0 384
Ag —0 175	Hg —0 379	Hg —0 467	Cr —0 491	Ag —0.442
Cr —0.187	Ag —0.404	Cr —0.467	Ag —0 498	Cr —0.508
Au —0 264	Pt —0.417	Pt —0 499	Hg —0 517	Pd —0 564
Fe —0.285	Cr —0 448	Ag —0.506	Pt —0 567	Hg —0 593
Pd —0 322	Pd —0 454	Au —0.567	Pd —0.567	Pt —0 611
Pt —0 374	Au —0.472	Pd —0.585	Au —0 588	Au —0.627
C —0.727	C —0.692	C —0.694	C —0.648	C —0.640

In order to compare these results with those of Neumann,[6] who measured the differences of potential between metals and aqueous solutions of their salts, the values he found are given in Table 8.

TABLE 8.[7]

	Volts.
Magnesium	+1.231
Aluminum	+1.015
Manganese	+0.824
Zinc	+0.503
Cadmium	+0.174
Iron	+0.087
Cobalt	—0.015
Nickel	—0.020
Lead	—0.095

6. *Zeit. Physik. Chem.* 14, 229 (1894).
7. This table is taken from Neumann's paper, *Zeit. Physik. Chem.* 14, 229 (1894). The values recorded were obtained with the solutions of the chlorides of the metals except in the case of Cu, Hg and Ag where the sulphates were used. The solutions of the chlorides of Bi, Sb, and Sn contained excess of acid.

TABLE 8 — (*Continued*).

	Volts.
Bismuth	—0.315
Antimony	—0.376
Tin	—0.085
Copper	—0.515
Mercury	—0.980
Silver	—0.974
Palladium	—1.066
Platinum	—1.140
Gold	—1.356

Comparing the values in the first column of Table 7 with those in Table 8, it appears that the one-tenth normal lithium chloride solution in pyridine is less positive toward Mg, Zn, Mn, Al, Co, Ni, and Fe than are the aqueous solutions of salts of these metals, whereas for all the other metals the reverse is the case. In column 5, Table 7, the values for Mg, Mn, Al, Fe, Co, and Ni show that toward these metals the one-tenth normal lithium chloride solution in water is less positive than are the aqueous solutions of their salts (compare Table 8), whereas the reverse is true of the other metals. And again, when columns 2 to 4, Table 7, are compared with Table 8 the same will be observed for the metals just mentioned. Bearing in mind that the lithium chloride content of the solutions in Table 7 remains constant and that these lithium chloride solutions are more positive toward the metals just mentioned and less so toward the other metals, than are the solutions of the salts of the metals toward the latter (Table 8), it seems natural to conclude that the effect noted is due largely to the substitution of the lithium chloride for the salts of the metals.

A comparison of columns 1 and 5, Table 7, shows clearly the striking effect which a substitution of pyridine for water produces on the electrochemical series, and also on the absolute values of the potentials. The intermediate columns 2 to 4 show by what gradations the values of column 1 pass into those of column 5. These effects are different for different metals as is shown by the accompanying Figure 1, in which ordinates represent differences of potential and abscissas per cent of water by volume contained in the solvent used.

It is interesting to note in Table 7 that magnesium maintains itself at the head of the series throughout and carbon remains at

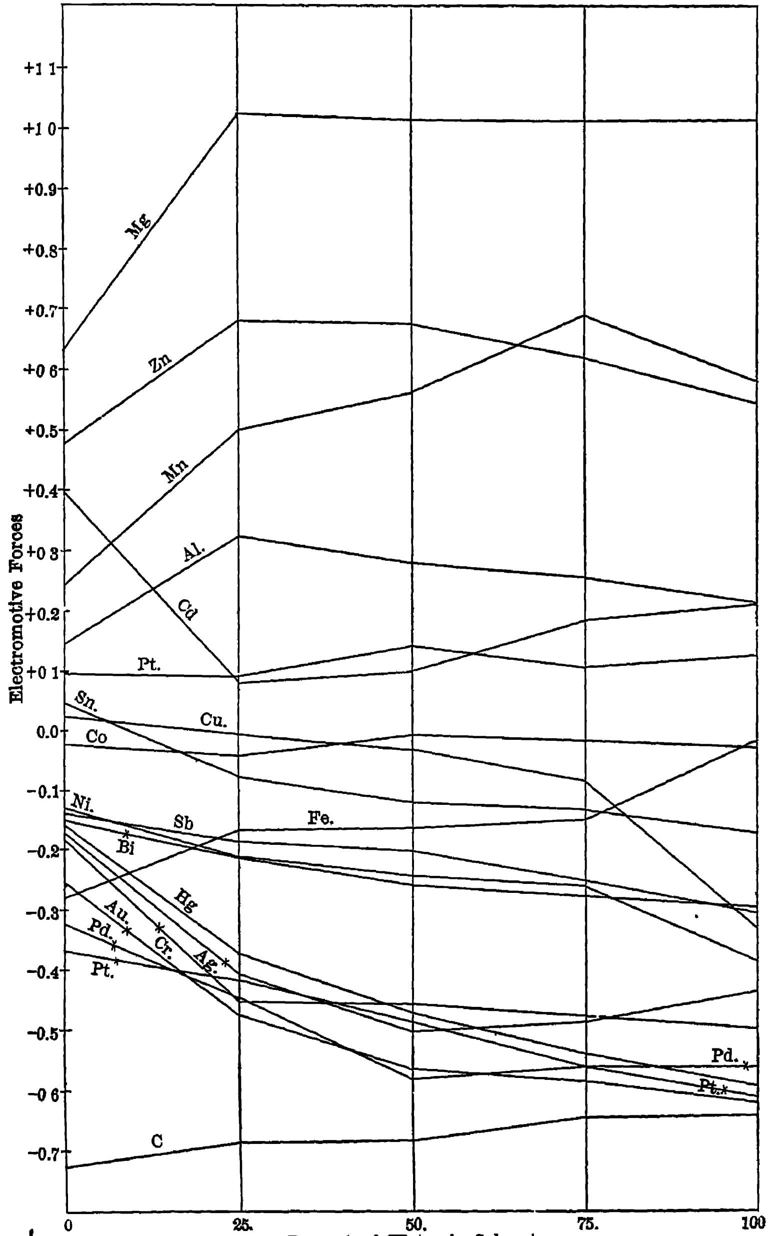

FIG. 1.—DIAGRAM INDICATING EFFECT ON RELATIVE E.M.F. OF VARYING PERCENTAGES OF WATER IN SOLVENT.

the foot, while the other metals suffer great displacements in some cases, and lesser ones in others. The absolute values of the potentials in columns 1 and 5 in Table 7 are in general quite different. In the pyridine solution the potentials are distributed over a smaller range, +0.638 for Mg and — 0.374 for Pt or a total difference of 1.012; while in the aqueous solution the difference is + 1.090 for Mg and — 0.611 for Pt, or a difference of 1.704, being a very material difference indeed. This is well brought out graphically in Figure 7.

Toward the noble metals the pyridine solution is more positive than the aqueous solution (compare columns 1 and 5, Table 7). This is on the whole what one would expect considering what is known concerning the affinity which these metals have for the elements of water on the one hand, and for pyridine on the other. Perhaps the most notable displacement of any metal in the series is that of iron. In column 1, Table 7, it stands below gold, whereas in column 5 it is next to lead. A solution of silver nitrate in pyridine may be boiled in contact with iron without precipitating the silver or even tarnishing the iron. This is quite in harmony with the electromotive behavior.

The difference of potential between a metal and a solution may then vary very greatly with a change in the solute as well as with a change in the solvent; and since this variation differs in the case of different metals for one and the same change in the electrolyte, either as to direction or magnitude, or both, the electrochemical series of the metals is frequently subject to relatively very considerable variations, and must not be regarded as something even fairly constant. The work of earlier experimenters, such as Fechner, de la Rive, Faraday and Wheatstone, and in more recent years the measurements of Sylvanus P. Thompson, all of which were made with aqueoūs solutions, serve to illustrate and to emphasize the same fact. A clear recognition of these changes in the electrochemical series is of great importance in electrochemical practice, particularly in the electrolytic separation of the metals.

A further detailed study of the differences of potential between metals and electrolytes from the stand-point of the chemical affinity existing between the metal and the electrolyte as the determining factor is being made in this laboratory; for though — since Faraday's law holds for all electrolytes as far as known at present — the difference of potential between a metal and an electrolyte is

recognized as a measure of the chemical affinity existing between them, the electromotive forces have not been foreshadowed from the affinities involved. The Helmholtz-Gibbs formula, to be sure, enables one to calculate the electromotive force of a cell from a knowledge of its temperature coefficient and of the thermal changes which accompany the chemical reaction that takes place in the cell when the circuit is closed.

DISCUSSION.

Dr. W. D. BANCROFT (Chairman): In deducing the van't Hoff-Raoult formula we remove from the solution a certain amount of the solvent by means of a semipermeable membrane and the assumption is made explicitly that there is no specific affinity between the solvent and the solute under these circumstances. These experiments of Mr. Kahlenberg seem to show that such an affinity does exist, and in that case it seems to me that these experiments throw a good deal of doubt on our present manner of determining molecular weights and solutions—a conclusion of course which does not terrify Mr. Kahlenberg in any respect.

Dr. H. E. PATTEN: Granting Doctor Kahlenberg's point that we have an affinity beween solvent and solute, this affinity is measurable by the heat of union, and can be converted into volts. While it is true that the e.m.f. varies from solvent to solvent, it can be discussed in terms of the heat of union between the solute and solvent for the particular concentration of electrolyte used. That nas not been done here for the very good reason that thermal data are not yet at hand. Of course we are limited by our inability to account adequately for the "bound energy," as Professor T. W. Richards states in his paper on the Relation of the Hypothesis of Compressible Atoms to Electrochemistry, presented yesterday; still much value attaches to discriminating use of heats of reaction and of solution.

For example, the single potential of aluminum against lithium chloride in water is given as + 0.204 volt, and nowhere in Fig. 1 rises above + 0.321 volt. In table 1, page 74, Vol. V, Transactions of the American Electrochemical Society, Mr. Mott gives + 1.45 volt as an experimental value for the single potential of aluminum, against aqueous aluminum chloride, derived from the decomposition voltage of aluminum chloride 3.45, as determined between platinum electrodes. The low value given by Doctor Kahlenberg is almost certainly due to a film upon the aluminum. Aluminum gives from 0.8 to 0.65 volt against platinum in aluminum bromide dissolved in ethyl bromide for the total cell; but if a current be passed for a time with the aluminum as cathode and the e.m.f. of the cell then measured, its total voltage is some 2.3 volts, and the true single potential of aluminum against this solution is seen to be + 1.1 volt. Aluminum deposited from this solution shows the same single potential, + 1.1 volt. Under proper conditions, then, it is possible to get the single potential of aluminum fairly well defined.

Prof. LOUIS KAHLENBERG: Concerning the question of semipermeable membranes, I should like to state that during the past year I have given this matter careful attention and have found that osmosis is really due to affinity. Semipermeable membranes, so called, do have affinity for solvents which they permit to pass. In my opinion there is good evidence for assuming that substances dissolve because they have affinity for the solvent and the solvent has affinity for them.

With regard to the remarks of Doctor Patten, I should like to say that he has simply given us his ideas as to how the problem might be investigated further.

As to the single potential of aluminum, it is a well-known fact that the figures ordinarily found in textbooks are quite high. The potential as actually found in practice is usually relatively low, which fact is frequently explained by the assumption that oxide films form on the plate. We might very well consider that the question of the exact potential of aluminum is still a debatable one.

The following papers were read in the absence of the authors by the section secretary.

THE LEAD VOLTAMETER.

BY ANSON G. BETTS AND DR. EDWARD F. KERN.

The voltameters which are employed for measuring the amount of electricity passing through an electric circuit are the silver voltameter, the copper voltameter and the oxy-hydrogen or detonating gas voltameter. These are named in the order of their scientific importance.

Since there is the least possibility of complications occurring in the deposition of silver from a concentrated neutral solution of silver nitrate, due to the monovalency of silver, the results obtained by using the silver voltameter are accepted as the most accurate. "This apparatus is universally recognized as the most accurate instrument of its class." (Oettel's "Exercises in Electrochemistry," p. 19.)

Before taking up the experimental part of this paper, a short account of the silver voltameter is given, as it is the standard apparatus with which the lead voltameter was compared.

"The uniform results obtained in the electrolysis of a concentrated neutral solution of silver nitrate have lead to the adoption of the silver voltameter as the standard instrument for measuring electric currents." (Carhart's "University Physics," p. 260.) "It is not employed for currents much larger than 1 ampere, because of the high cost of the material used for constructing the apparatus." For larger currents the copper voltameter is employed.

The results obtained by the use of the copper voltameter are not so uniform as those obtained by the silver voltameter, because the electrochemical equivalent of copper is so small, and also because the weight of copper deposited is a function of the temperature and of the current density at the cathode. But for ordinary current measurements, the copper voltameter is employed, as it has been found that with current densities of 1.5 to 14 amperes per sq. ft. of cathode exposure, the results are fairly accurate, enough so for ordinary experimental purposes, and, besides, it is an inexpensive apparatus.

"The high equivalent weight of silver and the fact that a very considerable quantity of metal is precipitated by comparatively feeble electric currents reduces the error of weighing the deposit to a minimum. The disadvantage which must be recognized in using the silver voltameter is that the silver is greatly inclined to separate as crystals, which are loosely attached to the cathode; consequently, strong currents cannot be sent through the apparatus for any length of time without the possibility of some of the deposited silver becoming detached. The electrolyte recommended is a moderately concentrated neutral solution of silver nitrate, about 15 to 20 grams of pure silver nitrate in 100-cc solution. The anode is a bar of pure silver, wrapped with muslin or filter paper, and the cathode is either a sheet of silver or a platinum dish." (Oettel's "Electrochemical Experiments," p. 38.)

Prof. Barker wrote that "it is evident that the results obtained by using a voltameter for measuring electric currents will be the more accurate in proportion as the electrochemical equivalent of the ion employed is higher." In most precise voltametric work, therefore, the silver voltameter is preferred, since the chemical equivalent weight of silver is 107.93. As a precaution he recommends that "the strength of current which is allowed to pass through the apparatus should not exceed 5 milliamperes per sq. cm cathode surface" (about 5 amperes per sq. ft.). (Barker's "Physics," p. 745.) In practice, however, a current density of 9 amperes per sq. ft. cathode exposure is employed by the Westinghouse Electric Company for calibrating electrical measuring instruments. (*U. of T. Record,* Vol. IV, p. 237.)

Up to within the past two or three years the results obtained by using the silver voltameter were thought to be accurate, but since then a number of experimenters have conducted careful researches for the purpose of finding inaccuracies which are apt to occur in using this apparatus. Several years ago the Reichsanstalt carried out a careful research and found that a source of error in using a silver voltameter was due to too great current density, and also to change of acidity or alkalinity of the electrolyte, caused by secondary reactions at the electrodes. (*Electrochemical Industry,* Vol. I, p. 36.)

Modifications of the silver voltameter have been described by Farup (*Zeit. f. Electro-Chemie,* Aug. 14, 1902) and by T. W. Richards, who found that with the ordinary type of silver voltameter the results obtained were not quite satisfactory. Richards pointed

out that the main trouble arises from the formation of complex ions at the anode, and which, when transported to the cathode, deposits too much silver. This he prevented by using a fine-grained porous cup for the anode compartment. Leduc stated that he hoped to prevent the formation of the disturbing complex ion by having a small current density at the anode. (*Electrochemical Industry,* Vol. II, p. 288.)

In the *Physical Review* of June, 1904, K. E. Guthe describes a series of experiments which he made in order to compare the different forms of silver voltameters. He found that "the usual form of silver voltameter is not a very reliable instrument for measuring quantities of electricity, but that the Richards porous-cup voltameter is the most satisfactory form for the purpose." (*Electrochemical Industry,* Vol. II, p. 288.)

Judging from the results obtained by these able experimenters and by several others, the inaccuracies resulting from using the silver voltameter are very small and for general purposes need not be considered. "The variation of the electrochemical equivalent of silver is from 0.011156, obtained by Mascart, to 0.011195 obtained by Pellat and Leduc. G. Van Dijk and J. Kunst found the mean value of 24 experiments to be 0.0111818, which the authors believe to be accurate to within one part in 10,000." (*Electrochemical Industry,* Vol. II, p. 117.)

For measuring the current for ordinary purposes, such as the calibration of electrical instruments and for finding the electro-efficiency of electro-chemical experiments, such accuracy as mentioned above need not be considered. This extreme accuracy need only be considered in establishing the standard ampere and coulomb, and for comparison in the determination of atomic weights of the metals by electrolysis.

"After all, the silver voltameter with its faults must be considered a standard instrument for measuring electric current until something better has been devised. In the meantime any of the much needed improvements in it will be welcomed." (*Electrochemical Industry,* Vol. I. p. 73.)

It is not the intention of the authors of this paper to try to replace the silver voltameter by the lead voltameter, but to describe the lead voltameter, and show wherein it possesses features which might be a means of its replacing the copper voltameter for technical purposes, such as calibrating electrical instruments and for comparison of electroefficiency of electrochemical methods.

The advantages which the silver voltameter possesses over the copper voltameter are, that the electroequivalent weight of silver is almost three and one-half times as large as that of copper, and that copper forms two compounds, in one of which the valency is twice as great as in the other. Under certain conditions of current density and temperature the copper compound of lower valency is formed, in which case the amount of copper deposited is too great. Silver also gives less trouble than copper, because the plates are less liable to oxidation. For ordinary purposes, however, the copper voltameter is sufficiently accurate, when the requirements as regards current density, temperature and composition of electrolyte are followed. Its general use is due principally to its being inexpensive, and also that the deposit which forms is smooth; so that short-circuiting due to growth of crystals does not occur, which property allows of its being left in the circuit for any length of time.

It has been found that the limits of current density in the copper voltameter are from 0.6 ampere to 14 amperes per sq. ft. (0.06 to 1.5 ampere per sq. dm.) of cathode surface exposure. By keeping within these limits, and by giving due attention to temperature, to composition of electrolyte, and to having good circulation of the electrolyte, the results obtained by its use are sufficiently accurate for general purposes. (Elb's "Electrolytic Preparations," p. 7; Oettel's "Electrochemical Experiments," p. 40.)

A glance at a table of electroequivalent weights of the metals will show that the metals which are deposited as solid metal on the cathode, and which possess high electroequivalent weights are silver (107.93), lead (103.46) and mercury (100.00). The first two metals on account of forming hard solid cathode deposits are well suited for voltameters.

The Lead Voltameter.

We are not aware that lead has ever been employed as a voltameter for measuring electric currents by any one except ourselves. Previous to the invention of the Betts process of refining lead alloys, the crystalline non-adherent deposit which forms on the cathode in the ordinary solutions was not suited for voltametric measurements. One of the claims of the Betts' patent is the formation of a smooth, dense, coherent, solid deposit of lead on the cathode in an acid solution of lead fluosilicate, which contains an organic reducing agent, such as gelatine, glue or pyrogallol, etc. This solution has been used constantly for over two years in the re-

finery at Trail, British Columbia. It is an inexpensive solution, easily prepared, and easily maintained. It conducts the current well, is non-volatile and is stable under electrolysis, which properties make it a suitable electrolyte for a voltameter. It also possesses the property that under ordinary conditions, when a soluble anode is used, no lead peroxide is formed, because the electrical potential required is so low, being in the proximity of 0.18 volt for concentrated solutions and about 0.40 volt for very dilute solutions, when using a current density of 10 to 15 amperes per sq. ft.

Several months ago the lead voltameter was compared by one of us with the copper voltameter, and the results were such that the lead voltameter has since been employed in our laboratory for measuring current efficiencies of electro-chemical experiments.

The results given in this paper are those obtained by comparing the lead voltameter with the silver voltameter.

Experimental Part.

The lead electrolyte was prepared by treating ordinary white quartz with commercial hydrofluoric acid (30 per cent acid) forming a solution of hydro-fluo-silicic acid (H_2SiF_6). Heating the solution of hydrofluoric acid caused more rapid solution of the quartz. White lead (basic lead carbonate) was added to the solution in the required quantity. It dissolved rapidly and completely with effervescence, and any hydrofluoric acid which did not react with the silica formed an insoluble precipitate of lead fluoride, which was filtered off. Lead fluo-silicate is a very soluble salt. It dissolves in about 28 per cent of its weight of water at 20 deg. C. The crystalline salt has the composition $PbSiF_6.4H_2O$.

The solution was diluted so as to contain 17 grams of $PbSiF_6$ and 7 grams of free H_2SiF_6 in 100-cc solution. After adding 1 gram of gelatine (dissolved in hot water) to 2000 cubic cm of solution, the electrolyte was rendered absolutely pure, in respect to metals which can deposit with lead, by electrolysing for several days, using electrodes of refined lead. The anodes were wrapped with two thicknesses of clean linen, so as to prevent the impurities from dropping off and floating in the electrolyte. The small amount of soluble impurities in the electrolyte was due principally to the impurities in the white lead used for making the solution. The electrolysis was continued for four days at temperatures between 17 deg. C. and 57 deg. C. using a cur-

rent density at the electrodes of 10 to 12 amperes per sq. ft. A small amount of "anode sludge" remained behind and in order to prevent it from being oxidized by the atmosphere and subsequently going into solution, melted vaseline was poured on the surface of the electrolyte. The deposit which formed on the cathode was smooth, dense and non-crystalline.

After purifying the electrolyte, about 800 grams of absolutely pure lead was made by electrolysis, using ordinary refined lead, wrapped with clean linen, for the anodes. The refined lead which was deposited on the cathode was further refined by reversing the current and redepositing it on new cathodes. The solution was protected from the atmosphere by a covering of melted vaseline. The purified lead was melted, cast into a thin plate and then rolled into sheets about 1/32 in. to 1/16 in. thick. The sheets were cut into strips of suitable size and used as anodes for the lead voltameter. No residue was left on dissolving the purified anodes by electrolysis.

The silver voltameter, which was used as the standard for comparison, was a glass beaker containing 500 cubic cm of a 15 per cent concentrated neutral solution of silver nitrate. The anodes were four rods of repurified silver, 5/8 in. wide by 3/16 in. thick, and an average length of 4 ins. giving a total active surface exposure of 12 sq. ins. (one side and two edges). The anodes were loosely wrapped with 3 thicknesses of clean linen, serving the double purpose of a porous compartment and to prevent any particles of silver from dropping off. The cathode was a sheet of platinum, having an exposure of 3 ins. x 3 1/2 ins., or a total exposure, both sides, equal to 21 sq. ins. The electrolyte at start and at finish of the experiments was neutral to fresh litmus paper.

The lead electrolyte used for the first series of experiments contained 13 1/2 per cent of lead fluo-silicate ($PbSiF_6$) and 6 1/2 per cent of free hydro-fluo-silicic acid (H_2SiF_6). It was prepared by diluting the purified electrolyte and then precipitating the excess of lead by pure sulphuric acid. The anodes were strips of the purified lead. Two glass beakers, each containing 500 cubic cms of the electrolyte, served as voltameters. (The action of the electrolyte on glass is small and the solution in a short time loses its originally small solvent action on glass. It may be kept in glass bottles.) The two lead voltameters were connected in series with the silver voltameter, and for convenience of approximately determining the current, an ammeter was also placed in the circuit.

TABLE NO. 1.—*Lead Electrolyte Contained* 13.5% $PbSiF_6$ and 6.5% *Free* H_2SiF_6.

A	B	C	D	E	F	G	H	I	J	K	L	M	
Experiment number	Duration of experiment.	Grams of silver deposited	Grams of lead deposited	Grams of lead dissolved	E M.F of silver cell	E M F of lead cells	C D per sq ft of lead cathode	C D per sq. ft of lead anode	Calculated amperes from silver deposits	Calculated amperes from lead deposits	Percentage error of the lead voltameters	Calculated electroequivalent weight of lead	Remarks on the lead voltameters.
1	1½ hr	5.8958	A5 6221	5 6910	0 36V	0 36V	16	16	0 9765	0.9715	—0 512	102.90	One anode and copper cathode
2	......	... ..	B5.6396	5 7002	....	0.14V	8.	9	. . ....	0 9745	—0 205	103.24	Two anodes and lead cathode
													Smooth, dense deposits
3	1½ hr.	5.7863	A5 5246	5 5970	0.36V	0 14V	7 5	8 6	0.9583	0 9547	—0 375	103 04	Two anodes and copper cathode
4	......	......	B5 5450	5.5840	.. . .	0 36V	15.	15.	....	0.9582	—0 010	103 43	One anode and lead cathode
													Smooth, dense deposits
5	2 hrs	7 8408	A7 5108	7 5758	0 36V	0.36V	16.	16.	0 9740	0 9734	—0 062	103 39	One anode and lead cathode
6	...	......	B7 5108	7 5871	.... .	0.15V	8.	9	....	0 9741	+0 010	103.47	Two anodes and lead cathode
													Smooth, dense deposits
7	2 hrs	7 6253	A7.3191	7 3693	0 37V	0.37V	15	15	0.9472	0.9485	+0.137	103.59	One anode and lead cathode.
8	......	......	B7.3221	7 3855	.... .	0.15V	7 5	8 5	... .	0 9489	+0 168	103 62	Two anodes and lead cathode
													Smooth, dense deposits
9	1½ hr	6.2287	A5.9600	6 0404	0.46V	0 16V	8	9.	1 0316	1 0290	—0 165	103 27	Two anodes and copper cathode
10	......	.. ...	B5.9605	6.0564	....	0.15V	8.	9	.. .	1 0300	—0.155	103.28	Two anodes and lead cathode
													Smooth, dense deposits
11	4 hrs.	16.6804	A15 9996	16 0720	0.47V	0.14V	8.	9	1 0360	1 0368	+0.077	103 52	Two anodes and copper cathode
12	.....	. . .	B16.0014	16.0816	.... ..	0 14V	8.	9	. ...	1.0369	+0.087	103 54	Two anodes and lead cathodes
													Smooth, dense deposits
13	1½ hr.	6.8652	A6.5815	6.6421	0.48V	0 27V	27	10	1 1370	1 1373	+0 027	103 47	Two anodes and lead cathode
14	. ..	......	B6.5812	6.6429	..... .	0 27V	27.	10	. . . .	1 1372	+0 018	103.46	Two anodes and lead cathode
													Smooth, dense deposits, except on lower corners.
15	1½ hr	9.3253	A8.9390	9 0217	0.64V	0.37V	37.	14	1 5444	1 5447	+0.019	103.46	Two anodes and lead cathode
16	......	......	B8.9419	9.0114	....	0.36V	37	14.	. . ..	1.5451	+0 045	103 49	Two anodes and lead cathode
													Deposit formed very rough and warty on the edges.
17	2 hrs	6 8566	6.5695	6.6445	0.42V	0 14V	10.	8	0 8518	0.8514	—0 047	103.41	Two anodes and platinum cathode
													Smooth, dense deposit.
18	2 hrs.	6 8754	6.5877	6.7097	0 43V	0 14V	10	8	0 8541	0 8538	—0.035	103.41	Two anodes and platinum cathode
													Smooth, dense deposit

TABLE NO. 2.—*Lead Electrolyte Contained* 8.5% $PbSiF_6$ and 2.5% *Free* H_2SiF_6.

A	B	C	D	E	F	G	H	I	J	K	L	M	
Experiment number.	Duration of experiment.	Grams of silver deposited	Grams of lead deposited	Grams of lead dissolved.	E M F of silver cell.	E M.F of lead cells.	C D per sq ft of lead cathode	C D per sq ft. of lead anode.	Calculated amperes from silver deposited.	Calculated amperes from lead deposited	Percentage error of the lead voltameters	Calculated electroequivalent weight of lead	Remarks on the lead voltameters.
19	2 hrs.	9.0470	A8.6678	8 7618	0 45V	0 32V	9.	10.	1.1238	1 1233	—0.044	108 41	Two anodes and copper cathode
20	......	......	B8.6663	8 7326	....	0 31V	9.	10.	....	1.1232	—0.058	108.39	Two anodes and lead cathode Smooth, dense deposits
21	3 hrs	13 4118	A12 8607	12 9875	0 50V	0.28V	9.	10.	1.1107	1 1112	+0.044	108.49	Two anodes and copper cathode
22	......	......	B12.8558	12 9343	. .....	0.27V	9.	10.	......	1.1107	0 000	108 46	Two anodes and lead cathode Smooth, dense deposits
23	2 hrs.	7.2780	A6 9716	7.0313	0.40V	0 42V.	22.	8.	0 9041	0 9035	—0 066	108 39	Two anodes and lead cathode
24	......	......	B6 9755	7.0272	....	0.41V	22.	8.	.	0 9041	0 0[illegible]0	108 44	Two anodes and lead cathode Deposit was rough on edges
25	3 hrs.	7.2738	A6.9695	7 0353	0.30V	0.38V.	14 5	5 4	0 6024	0 6022	—0 033	108 41	Two anodes and lead cathode
26	......	.... .	B6 9698	7 0468	.. ..	0 38V	14.5	5 4	.. ..	0 6022	—0 033	108.42	Two anodes and lead cathode Smooth, dense deposit
27	2 hrs	6 5278	6.2550	6.3494	0.41V	0.24V	10.	8.	0.8109	0.8107	—0.024	108.42	Two anodes and platinum cathode Smooth, dense deposit.
28	2 hrs	6 4864	6.2168	6 2939	0.42V.	0.24V	10.	8.	0.8058	0 8057	—0.012	108.44	Two anodes and platinum cathode Smooth, dense deposit

The electrochemical equivalents of silver and lead which were used are those given by Carl Hering in the *Electrochemical Industry,* Vol. I, p. 170: Silver = 0.001118 grams per coulomb, and lead = 0.0010717 grams per coulomb. Compared with the atomic weight of oxygen = 16.00, the atomic weight of silver = 107.93, and that of lead = 206.92, which gives the electroequivalent weight of lead = 103.46. These values give 4.025 grams of silver and 3.858 grams of lead per ampere hour. The value for silver is that which was adopted by the International Electrical Congress of Chicago, 1893.

Notes.

The three voltameters (one silver and two lead) were arranged side by side and were connected in series. All the electrodes, except the silver anodes, were attached to a strip of hard wood by means of binding-posts. This arrangement allowed all of the electrodes being placed in their respective electrolytes at the same instant, and also being removed and instantly submerged into beakers of distilled water (free from chlorides) which were placed directly back of the voltameters. The cathodes were at once detached from the strip, rinsed with distilled water, then with alcohol, allowed to drain and then carefully dried over a low Bunsen flame. They were placed in a desiccator over sulphuric acid, and as soon as cool were weighed. The lead anodes were washed, dried and weighed in the same manner.

Voltameter A in experiments No. 1, No. 3 and No. 4, and voltameter B in experiment No. 2 contained one anode and one cathode, one side of each exposed to electrolytic action. The size of each electrode was 2½ ins. x 4½ ins.; the surface exposed to electrolytic action was 9 sq. ins. The distance between electrodes was 1 in.

In all the other experiments, 2 anodes and 1 cathode was used. The size of the anodes was 2¼ ins. x 4½ ins.; the surface exposed to electrolytic action was 16 sq. ins. The distance between electrodes was 1 in.

The cathodes used in voltameter B in experiments No. 1 and No. 2, and both voltameters in experiments No. 3 and No. 4, were strips of lead, size 2½ ins. x 4½ ins. They were suspended in the electrolyte so that the active surface exposure on one side was 2½ ins. x 3½ ins., or 8¾ sq. ins. At the surface of the solution where the lead was exposed to atmospheric action it was slightly etched.

In the other experiments No. 5 to No. 8 and No. 11 to No. 14 the cathodes were exactly 3½ ins. long and were suspended ¼ in. below the surface of the electrolyte by a thin strip of metal about ¼ in. wide. This arrangement prevented the cathodes from being etched at the surface of the electrolyte where oxidizing action of the atmosphere takes place.

A thin sheet of copper, size 2½ ins. x 3½ ins., was used as cathode in the lead voltameter A in experiments No. 1, No. 2, No. 5, No. 6, No. 11 and No. 12. It was suspended below the surface of the electrolyte by a thin strip of sheet copper ¼ in. wide. It was found that there is no action of the electrolyte on the copper so long as it is the cathode and a current is passing. The deposit of lead which formed on it was just as smooth and as dense as that which formed on a strip of lead. This indicates that the copper was not dissolved, which might be expected as copper stands so much lower than lead in e.m.f. series. Copper, however, is dissolved by an acid solution of lead fluo-silicate when the solution containing a piece of metallic copper is allowed to stand exposed to the atmosphere. The only advantage which the copper cathode possessed is that a much thinner strip of metal was used, thereby decreasing the weight, which, when using a delicate balance, was an advantage.

In all the experiments, except voltameter A, experiments No. 1, No. 2, No. 3 and No. 4, two anodes and one cathode were used. This arrangement was found to be the most satisfactory.

The cathodes used for experiments No. 7, No. 8, No. 13 and No. 14 were strips of thin sheet lead, size 1 in. x 3 ins., giving a surface exposure (both sides) of 6 sq. ins., or a current density of 15 to 37 amperes per sq. ft. They were suspended below the surface of the electrolyte by a thin strip of lead 3/16 of an in. wide. The anodes for these experiments were strips of the purified lead size 2¼ ins. x 3½ ins., giving a surface exposure of 16 sq. ins.

In experiment No. 8 when a current density of 37 amperes per sq. ft. of cathode exposure was run, the deposit was dense and smooth, except on the edges where it precipitated as small warty formation. These lumps, however, were sufficiently coherent so as not to be detached during washing, drying and weighing the cathode.

When a current of 30 amperes per sq. ft. of cathode exposure is passed through the stronger electrolyte, a smooth dense, non-crystalline deposit formed. A current density of 27 amperes

per sq. ft. was used in experiment No. 7 and the deposit was perfectly smooth and dense; only at the two lower corners was there any inclination to roughness.

An electrolyte containing 8½ per cent of lead fluo-silicate and 2½ per cent of free hydro-fluo-silicic acid (6 per cent SiF_6 and 5 per cent lead) was used for experiments No. 11, No. 12, No. 13, No. 14, No. 15 and No. 16. In all these experiments, except No. 13, the deposit on the cathode was smooth, dense and non-crystalline. In experiment No. 13, when a current density of 22 amperes per sq. ft. of cathode exposure was used, the deposit was smooth and dense, except on the edges where it had a rough warty formation. This shows that the more dilute the electrolyte, the less is the upper limit of current density.

Platinum cylinders, 2 ins. high and 6 ins. circumference, were used as cathodes in the silver voltameter, and in the lead voltameter in experiments No. 9, No. 10, No. 15 and No. 16. The cylinders were flattened, forming a cathode measuring 3 ins. x 2 ins., or a surface exposure of 12 sq. ins. The current used in both the silver and the lead voltameter for these experiments was about 10 amperes per sq. ft.

All the deposits of lead formed in all the experiments, except No. 8 and No. 13, were smooth, dense, coherent and non-crystalline. The deposits were not dissolved from the cathodes, but were formed one on top of the other.

It might be mentioned that the reason for being so particular about purifying the electrolyte previous to the experiments, and for using such pure lead for the anodes was so as to be certain that any variation in the results would not be due to the impurities. Ordinarily, such care need not be exercised in securing such pure lead for the anodes. A good quality of refined lead is sufficiently pure for general purposes.

Conclusions.

The better form of voltameter is one with two anodes and one cathode. Suspend the cathode between the two anodes and below the surface of the electrolyte by means of a thin narrow strip of metal or wire, so as to prevent the action of the atmosphere on the lead at the surface of the electrolyte. This action may also be retarded by using an electrolyte which is less acid than that used in the experiments. Even with an almost neutral

solution of lead fluo-silicate its conductivity would be sufficiently high for a voltameter.

The lead deposit, unlike the silver deposit, is smooth, dense, coherent and non-crystalline. It has a density equal to that of cast lead, so that there is no danger of losing by washing, drying and weighing. The deposit, which forms even with high-current densities (20 to 25 amperes per sq. ft. of cathode exposure in a fairly strong electrolyte) is perfectly smooth, dense and non-crystalline, so long as the electrolyte contains about one part gelatine by weight in two to four thousand parts of solution. With age and by use, the gelatine slowly loses its reducing property. The appearance of the deposit indicates when more gelatine is needed, so that as long as the deposit forms smooth and non-crystalline none need be added. The gelatine is added by dissolving a small quantity in hot water, and adding it directly to the electrolyte. The moment it is added the crystallization of the lead is prevented.

A glance at the tables shows that the current density used within fairly great limits in the lead voltameter does not effect the results. In experiment No. 8 a current density of 37 amperes per sq. ft. was employed, and the results obtained agreed as closely with the silver voltameter as when lower-current densities were used. The limit of the current density seems to be controlled by the strength of the electrolyte and by its circulation. The more dilute the solution the less is the limit of current density which can be used. This is shown by the deposits which formed in experiments No. 7, No. 8, No. 13 and No. 14.

The lead voltameter is well adopted for obtaining electrochemical efficiencies of experiments which require long duration. Lead has the property in common with copper in that the deposit, which forms in some electrolytes, is perfectly smooth, dense and non-crystalline. It, however, possesses some advantage over copper in that the electrochemical equivalent of lead is over three times as great as that of copper.

Of great importance is the fact that while an acid copper sulphate solution in contact with copper electrodes contains varying quantities of cupreous sulphate. Lead exists in the solutions only as divalent ion. On this circumstance is founded our belief that the lead voltameter, properly used, will be found of extreme accuracy.

One advantage of lead over silver is its cheapness, so that with a small outlay a lead voltameter of any size may be constructed.

When necessary this will serve as an apparatus for accurately measuring strong currents of electricity, as much as 100 amperes, and even more, the limit being the size of the apparatus.

From an electrochemical point of view the lead voltameter also has an advantage over the silver voltameter in that lead stands very high in the e.m.f. series, so that the impurities which are ordinarily contained in refined lead will remain as "sludge" on the anode, whereas the purest silver is required for the construction of a silver voltameter.

The table shows that the lead voltameter compares very favorably with the silver voltameter, as the results are within sufficient limit of accuracy for most voltametric work. In the majority of the measurements the electroequivalent weights of the lead are almost theoretical. According to the most recent tables, the atomic weight of lead is 206.92, which makes the electroequivalent weight of lead equal to 103.46. These values in the table were obtained by the simple proportion: (Weight of deposited silver): (Weight of deposited lead) = 107.93 : x.

The difference in the amounts of lead dissolved from the anodes and deposited at the cathodes show that oxidation of lead took place to a serious extent, particularly when the solution had not had lead electrodes recently immersed in it.

For accurate work we recommend passing a current of pure carbon dioxide through the oxygen-free electrolyte in a covered receptacle. We do not think any further precautions will be necessary in washing and drying than we have used. It will be desirable to use fresh polished cathodes of lead or copper each time rather than redeposit metal on cathodes which have already been used. Should any oxidation of lead during drying take place with the formation of lead cxide, for example, the error caused by dipping such oxidized metal into the acid solution would be increased to 13 times (or the atomic weight of lead 207 divided by that of oxygen 16), the error caused by the simple oxidation.

This paper is far from complete. More work needs to be done in order to develop the possibilities of the lead voltameter, and to find out whether or not it is an accurate instrument. It is possible that it is as accurate as the standard silver voltameter, and for most purposes could be used in its place. It has cheapness and convenience of construction in its favor, as well as the formation of dense, coherent, non-crystalline deposits on the cathode.

CHLORINE IN METALLURGY.

BY JAMES SWINBURNE.

The essence of metallurgy, as practised for thousands of years, is the reduction of the oxide of the coveted metals with carbon, as such or as monoxide. Some metals, notably iron, exist in nature ready as oxide, but most of the others are found as sulphides. The sulphides are, therefore, roasted to convert them into oxides, and the oxides are reduced with carbon. Modern metallurgy broadly consists of the reduction of oxides to the metallic state.

In many cases this process involves very serious difficulties and losses. In smelting iron, the resulting metal is impure, as the ore and fuel contain objectionable elements which come out in the final metal. Zinc oxide needs a high temperature for its reduction, and the volatility of the metal necessitates closed retorts which wear out and leak, so that there is serious loss of metal. Lead sulphide is easily oxidised and reduced without carbon; but the silver present comes out alloyed with the lead; however, its metallurgy is very simple. Copper smelting, though exceedingly simple in broad principle, is excessively complicated in fact, owing to the presence of iron, arsenic, antimony, phosphorus, sulphur, etc., in the ore and fuel.

The smelting by reduction with carbon has, as every process must have, special difficulties of its own with particular ores. A good example is the mixed lead and zinc sulphides, containing silver and gold. Such an ore cannot well be roasted, to begin with, as the oxide of lead fuses and binds the ore into lumps or cakes. Even when it can be roasted, it cannot be smelted as a zinc ore because the lead oxide attacks the retorts. Besides, as an ore yielding zinc only, it may be poor, though the total value of the contents, could they be extracted, are high. Treated as a lead ore the zinc is in the way. Such an ore could only be smelted for lead in the blast furnace, where the zinc volatilises and comes down as oxide and is quite unwelcome. In some cases the zinc and lead can be separated to some extent by concentration. This means

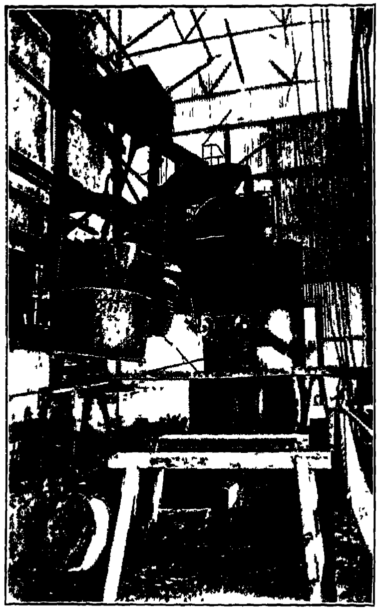

FIG. 1 — TRANSFORMER

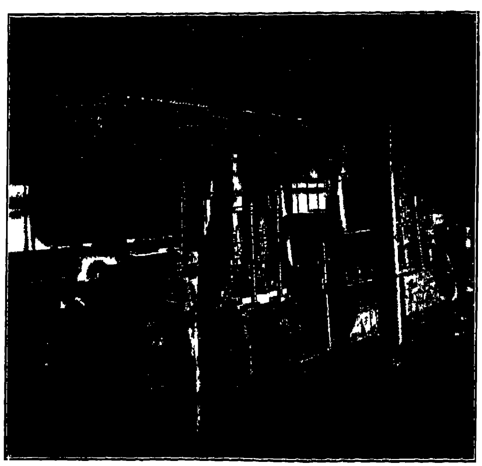

FIG. 2.— CHLORINE PUMPS.

that most of the ore is wasted altogether. Of the rest some is converted into a rich zinc ore contaminated with lead, and some into rich lead ore polluted with zinc. The silver generally prefers to go largely with the zinc. But many of the ores cannot be concentrated, and are at present best left buried.

Another example is antimonial gold. To begin with, there is often not enough stibnite for liquation, so concentration is necessary. But auriferous antimony sulphide is not much used. It can be treated as a simple antimony ore, and the antimony contains the gold, or it might be treated as a gold ore, the antimony being lost; but there is no process in use, as far as I know, which yields both the antimony and the gold separate.

The process I have the honor of bringing before you depends on the action of chlorine. Chlorine has been used in metallurgy before for attacking metallic gold; and salt has been employed for "chloridising" roasting. The present process is, however, a new departure, of quite a different kind, and is really a new form of metallurgy calculated to displace the oxidation and reduction processes now in use to a great extent. How far the replacement will take place depends eventually on economy only.

The principle of the process is treating sulphide ores, without previous roasting, with chlorine, so as to form chlorides of the metals, the sulphur being liberated as such. The chlorides are then electrolysed, yielding metals and recovering the chlorine. The chlorine thus goes round and round; and the process in its simplest form is analogous to separating the sulphur from the metals electrically, or changing the ore, at the mere expense of electrical energy, into its component metals and sulphur. This can in fact be actually done. In one of my first patents there is a description of electrolysing a bath of, for instance, zinc chloride and zinc sulphide with carbon anodes and fused zinc cathode. This gives off zinc at the cathode, and pure sulphur, not chlorine, at the anode. This simple method is not applicable to many ores on account of gangue, iron and other metals. It is mentioned to give a clear idea of the essence of the process.

In practice there are further modifications. The process naturally gives the best commercial return on ores that are refractory to other treatment; and complex ores yield mixtures of chlorides and gangue which could not be electrolysed straight off without intermediate treatment. The intermediate treatment is

always simple chemically, and consists in removing the gangue, and substituting zinc for the other metals one after the other till there is nothing but chloride of zinc left. This chloride of zinc is then electrolysed and the zinc and chlorine recovered. If there was no zinc in the ore, all the zinc obtained is used up again; but if there was zinc in the ore it is sold as zinc.

The action of chlorine on sulphides is generally very vigorous, and enough heat is generated to keep the mass hot. The transformer is something like a small cupola. It is an iron vessel lined with firebrick, and it contains mixed chlorides fused carrying the gangue and ore. The ore is run in at the top continuously and chlorine is pumped in at the bottom; sulphur coming off and passing over into a condensing chamber. There is no difficulty about pumping chlorine. Fig. 2 shows the actual pumps in use. Iron cylinders, pistons and valves are employed, and, as is well known, though not fully realized, dry chlorine, such as that from the electrolysis of fused chlorides, is a very harmless gas.

The transformer is tapped at intervals, and the mixed chloride and gangue run into water. Broken Hill slime, a waste product daily becoming more mountainous, has been chosen to work upon. It contains zinc, lead, iron, silver, manganese, sulphur and gangue. The gangue and lead chloride come out together, and the lead chloride is separated, the silver extracted, and the lead chloride electrolysed. The soluble chlorides are treated with chlorine, to get ferrous into ferric chloride, and the iron precipitated with zinc oxide or calamine. The manganese is got out separately or with the iron in a similar way. The zinc chloride is then boiled down and electrolysed. Fig 3 shows the evaporating vats, but it is not very clear. The electrolysis vat is simply an iron case lined with fire brick, and is kept hot by the excess of the electric over the chemical energy.

The history of the process is simple. The first patents were in 1897, and the process was tried in the laboratory and everything worked well. It was then tried on a pound scale and worked. A works was taken in Milton, and large scale experiments on electrolysis and handling of chlorine were carried out. A 3,000-ampere electrolytic vat was run continuously for three months. Facilities were wanting there. Mr. A. J. Smith, the general manager of the Castner-Kellner Company, saw a chance of a future in the process, and the company made arrangements for us to put down an ex-

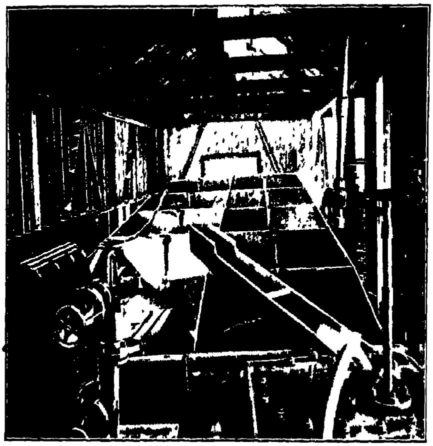

FIG. 3 — EVAPORATING VATS.

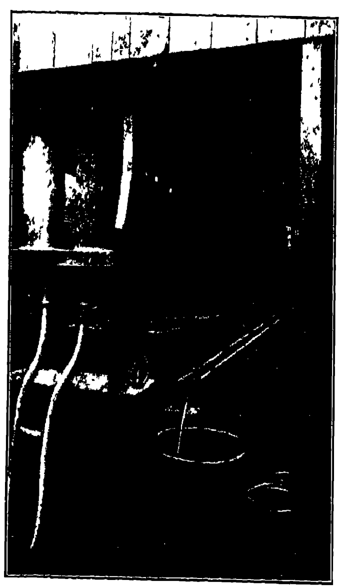

FIG 4 — DRYING TOWERS.

perimental place next door to their works. This was done and the transforming was proved on a large scale. We have repeatedly learned from the technical journals that the chlorine reaction does not take place, and that fused zinc chloride cannot be electrolysed. In fact people have proved it with test tubes. The Castner-Kellner Company, however, were able to investigate the working of the process, and to inspect the transformer consuming at the rate of 30 tons a week. They were well enough satisfied with the results to arrange to take the works over, acquiring a license to make chloride of zinc. They thus use the whole process except the electrolysis, as they have a supply of chlorine from the soda works. They will run a 10,000-ampere vat for demonstration, but otherwise they will sell every metal but zinc, the zinc being sold as chloride. The only difference in the process is that zinc chloride must be much more highly refined for the market than for electrolysis, as a trace of manganese, for example, would spoil the color, but would do no harm in electrolysis. The chlorine is also damp, and has to be dried before being pumped.

Fig. 4 shows the drying towers. They contain zinc chloride. The Castner-Kellner Company are reorganizing the works, and reconstructing it in many details, and will probably have the first unit, dealing with 30 tons of ore a week, running this fall.

It is of little use repeating in one paper what is already accessible elsewhere. I have gone into much greater detail in a paper before the Faraday Society, June 30, 1903. This paper gives rough approximations as to profits, costs, and explains which ores can be treated and which cannot. I must also refer to a paper by Mr. Ashcroft (*Trans.* Inst. Min. & Met. Vol. IX), who joined in 1898 and collaborated with me up to last year, working out the practical development of the process.

A good deal of work has been done recently on the treatment of ores with little metal content, such as copper ores running under 3 per cent, and copper nickel and cobalt ores. These modifications have only been tried on the small scale, and so it is too soon to speak yet, but apparently low grade copper, and nickel, cobalt and of course their mixtures, and copper zinc ores of low content will prove amenable. Such interesting puzzles as the treatment of speiss from copper smelting works, and the smelting of antimony gold ores, have already yielded satisfactory solutions on the small scale, and fahlerz of various compositions is likely to be amenable to simple and profitable treatment.

Discussion.

Prof. W. D. Bancroft (Chairman): The most interesting part of this paper seems to be that on the commercial scale there is no electrochemistry involved; that is, the process works well if that is eliminated, and is successful because the Castner-Kellner Co. has a large excess of chlorine for which it has no market, and thus makes zinc chloride. The case cited hardly proves the actual value of the process in ordinary metallurgical work, because it would hardly be feasible, so far as one can judge, to make caustic soda by electrolysis of salt in every place in which it was desired to use the process.

Mr. S. S. Sadtler: The process mentioned seems to be quite simple. Some may remember seeing the process very completely described in a copy of the *Engineering and Mining Journal.* A half-page was devoted to diagrams showing the different steps, and it seemed more complicated than shown here

Professor Bancroft: All the metals have to be removed by filtration from fused anhydrous zinc chloride. This must present serious difficulties, but it is said that this problem has been solved.

On motion, the Section then adjourned.

ALUMINOTHERMICS.

BY DR. HANS GOLDSCHMIDT.

A new means of creating high temperature is apt to lay the foundation for more or less important industrial developments. Legends tell us that there was once a time when humanity existed without fire until Prometheus brought the divine fire to the dwellers of the earth and thereby laid the foundation for civilization. In making a step forward across thousands of years, look at the industries before the employment of black coal — before it became known that coal was combustible matter. We perceive that our whole modern technical knowledge is based on the creation of heat by the combustion of black coal. A new fire was supplied by Volta in the electric arc, but it took centuries before the invention of dynamos enabled us to utilize the heat power supplied by electricity, by means of the electric lamps and furnace. We perceive that the fundamental idea and the mere production of heat do not by themselves supply practical results, and that it is only the application that determines the real value, which it sometimes takes many years to detect. To these known means for the production of high temperatures, a new one is now added — the so-called "thermit process."

Although I may assume that most of you know the principles of the process, you will nevertheless permit a short explanation of its essential points. Just as generations passed mineral coal without detecting its combustible properties, it was not known heretofore that aluminum belonged to the combustible products, which under certain circumstances, once ignited, continues its own combustion. Aluminum in a divided state only wants to be mixed in certain proportions with a chemical compound containing oxygen, so-called "oxide," for instance — oxide of iron — in order to obtain a heating compound now known as *thermit,* which name is copyrighted.

It is self-evident that the technical details of its preparations required special study, just as much as the preparation of gunpowder or dynamite. The particular character of this burning thermit is quite different from that of explosives, the effect of which is always

based on instantaneous production of great masses of gas. No gas whatever is produced by thermit. The mass continues the combustion within itself without a supply of air or heat from outside. The chemical reaction is of the simplest, so that the first chemical lesson might commence with an explanation of these simple phenomena. Even to a layman they are quite intelligible, as only three elements intercommunicate. First, aluminum, which is mixed, secondly, with a combination of metal — for instance, iron — and thirdly, oxygen, which combination is called "oxide of iron." If this thermit compound is ignited, nothing except a separation of the oxygen from the iron and a chemical combination with the aluminum results, forming, therefore, aluminum oxide, and setting free or melting out the iron.

When thermit has been burnt down in a crucible, the aluminum oxide, also called "corundum," floats on the top as a slag; the iron lies at the bottom as a regulus.

I have not yet mentioned the most remarkable and important properties of thermit: Firstly, its high combustion temperature, about equal to that of the electric arc — say 3000 deg. C.— and secondly, the speed of the reaction. A density of energy of the heat supply is produced, which has up to the present time never been obtained by other means — not even by the largest electric furnaces hitherto constructed. In this lies the principal reason of the utilization of thermit. Independently from the quantity brought to reaction, the duration of the combustion in the crucible remains about unchanged, say from one-half to one minute. This is explained by the speed of the reaction peculiar to thermit. In a large crucible a large melting zone is formed, which again on the large surface speedily ignites the surrounding particles. Thermit must be ignited by a so-called "ignition powder" of low-ignition point, but producing a high temperature, which in its turn ignites the thermit, as the latter is very difficult to ignite and in consequence presents no fire risk. Thermit thrown into an open hearth fire will not burn, because the temperature of this fire is insufficient to ignite thermit.

Two parts of weight of thermit give one part of pure, mild, malleable iron. If 200 kilograms of thermit are ignited in one crucible, hardly a minute afterward one has at his disposal 100 kilograms of liquid, superheated, mild steel. By no other known means has it hitherto been possible to produce liquid steel in so speedy and simple a manner. No apparatus is required. A crucible lined with highly-

refractory basic material, such as magnesia, is all that is required. If it were desired to obtain the same heat efficiency, about 200 horsepower would be required during one hour. It is easy to understand from this fact the very peculiar heat source with which thermit supplies us. Out of these properties of thermit, we can deduce its applications.

As already mentioned, the development, but more still the introduction, was the work of years. Although the practical application of the process has already made strides, nevertheless, infinite possibilities of new developments will present themselves. I can only mention here the most important ones and only partly touch on some of these, as thermit finds uses in a great variety of applications. The principal branches are the following:

1). Metallurgical applications:
  a). Production of pure carbonless metals and alloys.
  b). Applications in iron and steel foundry practice.
2). Utilization of the aluminogenetic slag, corundum, so-called corubin:
  a). For grinding purposes.
  b). For ceramics in the process of Dr. Buchner, Mannheim.
3). Hard soldering, applications of "sinter" thermit.
4). Welding process.
  a). Pipe welding.
  b). Rail welding.
    i). Embedded trolley rails.
    ii). Exposed T-rails.
    iii). Third rails.
  c). Application of thermit or thermit steel for repairs of all sorts; in particular for maritime repairs and spare castings wanted in a hurry, welding broken bosses of rolls, etc.
5. Application for cooking for camp use.

As above mentioned thermit separates pure metals from their oxides — not only iron, but also chromium, manganese, ferro-titanium, ferro-vanadium, and many others. In this way processes were elaborated to produce on a large scale carbonless metals of a purity not hitherto obtained. A long-standing wish of metallurgists was fulfilled, which electricians could not satisfy in their furnaces, in spite of long-continued studies. The metallurgists now pro-

ceeded to apply these pure metals in practice. Their successful studies on this subject cannot be sufficiently appreciated.

Chromium has first attracted particular attention, and American works are using it in considerable quantities, particularly in the manufacture of high-speed tool steels, whose efficiency is proved by turnings of the thickness of a finger. The usual addition is about 6 per cent chromium besides tungsten, and the carbon contents must be kept as low as possible. For projectiles, carbonless chromium is also used — in short, anywhere that chromium steel of accurate composition is required.

In nearly the same quantities pure manganese free from carbon is used, principally for alloying with copper, besides for the casting of nickel and bronze. It is much used for propellers, which must not contain iron, a condition which precludes the use of ferro-manganese.

Lately molybdenum and ferro-vanadium have been placed on the market. Ferro-titanium has been used regularly for several years by some steel works. This ferro-titanium is introduced into liquid cast-iron in the ladle, by means of the so-called box reaction. In this way highly-heated ferro-titanium is separated out at the bottom of the ladle, which alloys in *statu nascendi* with the contents of liquid iron. The reaction taking place in the midst of the bath, the latter is more thoroughly stirred or poled than is possible by other means. Through the introduction of a small quantity of titanium, which binds the nitrogen, the composition of the bath undergoes a chemical improvement. Impurities, such as slag and others, are driven up, and the bath is further purified.

It is remarkable that the sulphur contents are appreciably reduced. I will mention two analyses.

Cast-Iron.	Before Ti. addition.	After Ti. addition.
No. I.	Mn. 0.36	Mn. 0.30
	S. 0.19	S. 0.09
	Ti.	Traces.
	Before Ti. addition.	After Ti. addition.
No. II.	Mn. 0.66	Mn. 0.64
	S. 0.09	S. 0.07
	Ti.	Traces.

Of late the contents of the boxes are pressed into solid moulds, preventing the possibility of their getting unmixed and producing a

prefectly regular reaction. The iron becomes considerably more fluid and it can, therefore, be cast at a lower temperature and will show very much less tendency to form shrink cavities. The process has been introduced in the course of the last year in a number of foundries, in particular for cylinder castings, high pressure valves, etc.

The possibility of reviving liquid iron or steel locally by this "box reaction" has led to a further application, which has become very important for foundry purposes. In casting steel ingots of more than 10 tons, the piping which occurs in the head and which extends through the upper third of the block causes a great deal of trouble. A box containing from 10 to 20 pounds of thermit, according to the size of the ingot, is introduced just as late as the hardening of the surface will allow its insertion. The reaction will revive the steel in the head and allow the piping to be filled up with fresh steel.

A still more extensive use of box reaction consists of the introduction of thermit into the risers. Formerly a small can of suitable shape was built into the bottom of the risers. Then it was thought a simplification to insert the box at the end of a rod, into the liquid iron, as it rose. Now, in a number of works, the thermit is simply wrapped in paper and thrown on the rising liquid metal. This process is equally applied in the iron and steel casting practice. For cast-iron the wrapper should contain, at the bottom, a pinch of ignition powder, as the temperature of liquid cast-iron is insufficient to start the thermit ignition. Liquid steel does not require ignition powder. Many faulty castings will be avoided by this application.

Having shortly touched on the metallurgical aspect of aluminothermics, before proceeding I wish to mention the uses of corundum slag. This artificial corundum, so-called "corubin" (registered trade-mark), is very different from those of the natural product, and its properties are much more valuable. The cause is the chemical composition of the two materials. The natural product contains various impurities, such as oxide of iron, silica — even small quantities of water in chemical combination. On the other hand, the aluminogenetic corundum is nearly free from all these, and in particular absolutely free from water. This is no doubt the cause of its greater hardness compared to the natural product. In consequence, corubin is used for emery wheels.

The most curious, and in a way, epoch-making application is

one of a colleague of mine, Dr. Buchner, of Mannheim. He found that this material had an exceedingly low elastic coefficient and does not lose this property when mixed with a fire-clay binder. In this way he managed to produce vessels for chemical purposes of entirely different properties than the earthenware vessels in use up to the present. You know how easily a porcelain or earthen vessel cracks when exposed to even small changes of temperature. Those made of corubin behave differently. They can be heated to red heat and cooled suddenly with water without showing any tendency to crack. For instance, for hot muriatic acid only enameled vessels could heretofore be used, which were not reliable and of very limited usefulness. Corubin offers, therefore, almost unlimited advantages to the chemical industry. Its highly-refractory qualities have introduced it as a coating for bricks and tubes exposed to high temperatures. For these purposes only the corubin resulting from the chromium reaction is utilized, of which sufficient quantities are available, in consequence of the large consumption of pure carbonless chromium. This corubin requires a special preparation before being used. The aluminogenetic corubin has proved itself a valuable product for making crucibles for the thermit welding process. Such crucibles, made according to a certain receipt, will stand from 50 to sometimes 100 reactions.

The aluminogenetic welding process, which I shall now deal with, offered this peculiar difficulty. A new fire had been discovered, over which one had not as yet gained entire control. It is a peculiar fire, which is solid and without flame, and which gives half its weight in the form of liquid metal and the other half in the form of overheated slag. In the first experiment, iron rods were steeped into the liquid fire, in order to heat them like in a smith's hearth. Then a thermit was produced which did not liquefy, but only sintered and produced white heat. This, however, showed itself more applicable to hard soldering and less to welding. For the former application it is more handy than a charcoal fire or gas. For welding purposes a different process was found. The pieces were butted between clamps, a mould put around the joint and into this the liquid mass was poured over the top of a crucible. After obtaining welding heat, the clamps were tightened. It was determined by experiments what quantity was necessary for each section and the results were tabulated.

The process, of course, does not claim to replace the smith's fire, but to supply its place where the smith's fire would be insufficient. For instance, it has proved itself very valuable in welding lengths of pipes in installing whole systems. It competes successfully with flanged joints, particularly where the pipe system is used to carry fluids or gases which easily destroy their packings; especially for oils, alkalies, acetylene, and refrigerators; naturally also for high-pressure systems of all kinds. The welded joint is fully as strong as the pipe itself. Recently the manner of welding pipes into "T" shapes has been worked out. It required some little practice to successfully handle the material, but as it obviates keeping a large stock of various sized "T" pieces, it is of considerable importance, especially in outlying districts, mines, etc. The action of the liquid in running out over the lip of the crucible, on to the piece to be welded, is peculiar. The slag corubin flows out first. This solidifies instantaneously on the metallic surface, so that the thermit steel which follows and does not liquefy the thin layer of slag does not touch the welding surface and, therefore, cannot burn through the wall of the pipe. If the aluminogenetic iron were to come in contact with the metallic piece, it would fuse with it. After the weld is made, the slag and thermit can, therefore, be easily removed with a hammer and the welded joint does not require machining.

I now come to one of the principal applications of the process — the welding of rails. The track of a street railway, in consequence of the bed on which it lies and the way in which the rails are held in the pavement, has to be considered from a different point of view than the exposed track of a steam road. The former at present, has received more attention. Even laymen may know that there are hundreds of mechanical joints, none of which have given entire satisfaction. The demand of engineers for a really continuous rail, that is to say, having everywhere practically the same section, and undergoing in all parts the same amount of wear and tear, is justified. For electric railways using the rails for conducting the return current, this is an additional advantage. Copper bonds are only an imperfect conductor of electricity, because, although when new and well fixed, they give satisfaction, still, in course of time, the skin resistance increases so much that the bonds require renewal. Otherwise the so-called "electrolysis" would take place, causing not only leakage of current, but inter-

ruption in gas and water pipes. These, on account of the large extent of the electric systems in the United States, have received more attention and study here than abroad. A weld offers, of course, the greatest security for efficient conductivity.

To come to the practical side, the first welds were made about four years ago, in the same manner which I described when talking of the welding of pipes. The crucible was emptied by pouring over the lip; the rail ends brought by this means to welding heat were forced together by a strong pair of clamps, so that the section was completely butt-welded. Afterward the process was considerably simplified by, in a way, reversing it and letting the thermit iron run out first, followed by the corundum. Over the mould is placed a conical crucible, plugged in the manner customary in our process. As soon as the charge in the crucible is burned down, it is tapped from the bottom and the iron runs into the mould made of refractory material. The highly-overheated thermit steel fuses with the foot and web of the rails to one homogeneous mass, thus forming an immovable solid shoe. On account of the high temperature, a few pounds are sufficient; the diameter of section is, therefore, only slightly increased, an advantage which is essential. The heat of the corundum that follows is utilized at the same time to bring the heads of the rail to welding heat. In this way the section is heated equally all over, which is material, to avoid bending of the rails. They will remain in absolutely the same position as when put down before welding and are not held by special clamps or bolts. With new rails and under special conditions, a butt-weld is sometimes demanded. This can be obtained by placing the rail ends into a strong pair of clamps. With well-imbedded rails, and especially where they are anchored, a butt-weld is superfluous. With old rails, the life of which can be considerably lengthened by welding, the use of clamps is impracticable.

I wish to give some details regarding the strength of the welded rail. It is about 80 to 100 per cent of the rail itself; you will admit this is a very satisfactory result. The resistance of a butt-welded and not butt-welded rail to vertical pressure from above is about the same. The resistance to pressure will not, however, satisfy critics as long as it is to be feared that the heads of the rail might get softer through having been brought to welding heat, and develop the well-known hollows at the rail ends. This objection must be treated quite seriously, as all the advantages of the process would be of no avail against such a fault. As a matter of fact,

the weld undergoes no change of this or any other sort. The Great Berlin Street Railway has had joints in service for two years and after more than three-quarters of a million cars, not counting the very numerous trailers, had passed over them. The head has remained perfectly level and even with the use of a ruler no unevenness is discovered. This fact disposes most effectually of all fears. Any one can have this fact confirmed, if of two rails of identical material he will have one treated with thermit and then have test-rods cut out of both. Tensile strength and elasticity will be found equal and unchanged. Theoretical explanations can be easily adduced and have been confirmed by the highest authorities. As the operation takes place without the air having access to the welding zone, a chemical change such as would occur in a coal or gas fire is impossible. As in this country there has been as yet no opportunity to meet this objection by practical proof, I may mention the reply I received from a prominent German street railway engineer to my request for small plaster casts of thermit-welded joints that had been in the ground for more than three years. He said he failed to see the object of such casts, as it was well known that the joint would not show any difference from any other part of the surface of the rail. While two years ago only 3000 joints were welded, last year the number reached 20,000, which has already been exceeded in the first half of the present year.

In this country it was only possible to begin the exploitation of the process quite recently, as in consequence of the custom duties it had been found impossible to import thermit from abroad.

Regarding welds of exposed "T" rails, few experiences are at present available. The first practical tests were made this summer at Budapest, on behalf of the Hungarian Government Railway. Lengths of 72 meters, about 240 ft., and even one length of 150 meters — about 500 ft.— were welded together. The tests are being continued at the present moment on other railroads.

A special rail joint calling for remark is that of the third rail. The copper bond in this case is also unsatisfactory, particularly as sometimes very strong currents have to pass through it. Besides, it lies exposed and, therefore, offers great temptation to thieves. In many cases it is sufficient to weld a small bond of thermit steel between the two feet of the rail. A piece of tubing is placed over the mould and charged with thermit. This is ignited and burns down by itself without a crucible being used. The price of such

bonds is much below that of copper bonds. In this way, for instance, a suburban track 13½ miles in length was welded and has stood the test of one winter's low temperature. The joint is mechanically strengthened by one fish-plate on the side opposite to the bond. The Metropolitan Underground Railway of Paris, France, has welded about 20 miles of third rail; in this case the whole section was welded and, of course, no fish-plates were used.

Thermit, however, is by no means used only for small welds, such as rails and tubes. By the possibility of burning down the largest quantities of thermit and of obtaining at a moment's notice any quantity of liquid steel, the process is particularly useful for the largest weld, such as are necessary in ship repairs. A broken stern post, a cracked crank-shaft, can be welded without removing it from its bearings. The results obtained can be appreciated from a number of lantern slide pictures which I shall have the pleasure of showing you at the end of the lecture.

In the Russian-Japanese war thermit has played an important part, particularly on the Russian side. After the first attack of the Japanese on the Port Arthur fleet, orders for several tons were received from the Russian Government. These orders have continued to increase ever since. The remarkably speedy repairs of Russian ships are, according to accounts received by me, in many cases due to thermit welds. The Japanese have, of course, also used thermit, but as before the war it was less known there than in Russia, its possibilities have not received the same attention. Of course some practical experience is imperative before large quantities of thermit can be successfully handled. This experience is, however, not difficult to acquire. In far-off countries thermit has come into constant use, although no experienced mechanics were available, and the engineers had to teach themselves by closely observing the rules laid down in the pamphlets. Of course it is just in such countries where machinery is difficult to obtain that thermit is of inestimable value. By its help urgent spare castings can be made at once out of thermit steel; for instance, cog-wheels.

For a special sort of repair it is used in rolling-mills for welding bosses on rolls. The surface on which the new boss is to be welded is brought to fusion heat by first pouring a little liquid iron on it, which is covered by a quantity of thermit. The latter is ignited and enables the liquid metal which is then poured on it to evenly weld to the roll.

In conclusion, I will mention an entirely novel application. In consequence of a suggestion of mine, the "Deutsche Munitions & Waffenfabrik," Karlsruhe, has constructed a very handy cooking and roasting stove, allowing a speedy warming of food and drink in the open air, by means of thermit, without a flame. This can be of great value in campaigning — for instance, on outpost duty where cooking may be done without divulging one's position to the enemy. To avoid misunderstanding, I may as well mention at once that thermit cannot be adapted for fuel on a large scale, for instance, on torpedo or other boats. In this respect it cannot compete with anthracite, as 1 kilogram of thermit gives about 450 calories, while anthracite gives about 7000. The value of the new heat producer lies in the speed of the combustion and the enormous heat developed, or, as I said at the beginning, its density of energy, not in the great number of available calories. For heating purposes in the ordinary sense, it can, therefore, only be utilized on a small scale, for very specific purposes and where, besides, a particularly low price is not of importance. In such cases the ordinary heat producers cannot be employed with economical results, while thermit, under such conditions, is burnt as in a calorimeter and can be utilized almost quantitatively.

"The new fire" in the short time of its existence has obtained a quite appreciable introduction, but only the initial work has been done, and the present field of its usefulness — in particular for rail-welding purposes — will increase enormously. In the course of time new fields of utility will be discovered for a process which produces in so simple and speedy a manner, without bulky equipment, such enormous temperatures.

Thursday, September 15, 1904.

Joint Session of Section C with the American Electrochemical Society, Thursday, September 15, 1904.

Chairman Carhart called the Section together at 9:30 o'clock.
The following paper was read by the author.

THE SILVER VOLTAMETER.

BY DR K. E. GUTHE.

1. According to Faraday's law of electrolysis, a strict proportionality exists between the quantity of electricity passing through an electrolyte and the electro-chemical reaction produced by it. The latter may, therefore, serve for the measurement of quantity of electricity. We call the instruments employed for this purpose "voltameters" though the name "coulometers" proposed by Richards seems to be a far more appropriate one.

A good many different types of voltameters have been used, for example, the gas voltameter, in which the volume of the liberated gases is measured, or the iodine and the iron voltameters in which the electro-chemical change is measured by titration. The usual method, however, is the determination of the weight of a substance deposited at one of the electrodes by an electric current[1]. Of the last the copper voltameter and the silver voltameter are the best known types.

The investigations of F. and W. Kohlrausch[2], Rayleigh and Sidgwick[3], Gray[4], Schuster and Crossley,[5] and Glazebrook and Skinner[6] have proved that the silver voltameter is by far the most reliable instrument of this sort and that it will give results accurate to 1 in 5000, if certain specifications as to its construction and treatment are closely followed.

2. This led to the adoption of the silver voltameter as a standard for the measurement of electric current by the International Electrical Congress held at Chicago in 1893. Though the ampere was defined as one-tenth of the unit of current of the c.g.s. system of

1. A description of some unusual types is given by Danneel, *Zeit. f. Electroch.*, vol. 4, p. 154, 1897.
2. Fr. and W. Kohlrausch, *Wied. Ann.*, vol. 27, p. 1, 1886.
3. Rayleigh and Sidgwick, *Phil. Trans.*, vol. 175, p 111, 1884.
4. Gray, *Phil. Mag.*, vol. 22, p. 389, 1886.
5. Schuster and Crossley, *Proc.* Roy. Soc., vol. 50, p. 344, 1892.
6. Glazebrook and Skinner, *Phil. Trans.*, vol. 183, p. 567, 1892.

electromagnetic units, it was added, that it "is represented sufficiently well for practical use by the unvarying current which when passed through a solution of nitrate of silver in water in accordance with standard specifications, deposits silver at the rate of 0.001118 gram per second." This value is called the electrochemical equivalent of silver.

The specifications referred to above were prepared by the National Academy of Sciences and legalized in the United States in 1894. They read as follows:

In employing the silver voltameter to measure currents of about one ampere, the following arrangements shall be adopted:

The kathode on which the silver is to be deposited shall take the form of a platinum bowl not less than 10 cms in diameter, and from 4 to 5 cms in depth.

The anode shall be a disc or plate of pure silver some 30 sq. cms in area and 2 or 3 mms in thickness.

This shall be supported horizontally in the liquid near the top of the solution by a silver rod riveted through its center. To prevent the disintegrated silver which is formed on the anode from falling upon the kathode, the anode shall be wrapped around with pure filter paper, secured at the back by suitable folding.

The liquid shall consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

Method of making a measurement.—The platinum bowl is to be washed consecutively with nitric acid, distilled water and absolute alcohol, it is then to be dried at 160 deg. C., and left to cool in a desiccator. When thoroughly cool it is to be weighed carefully.

It is to be nearly filled with the solution and connected to the rest of the circuit by being placed on a clean insulated copper support to which a binding screw is attached.

The anode is then to be immersed in the solution so as to be well covered by it and supported in that position; the connections to the rest of the circuit are then to be made.

Contact is to be made at the key, noting the time. The current is to be allowed to pass for not less than half an hour, and the time of breaking contact observed.

The solution is now to be removed from the bowl and the deposit washed with distilled water and left to soak for at least six hours. It is then to be rinsed successively with distilled water and absolute alcohol and dried in a hot-air bath at a temperature of about 160 deg. C. After cooling in a desiccator it is to be weighed again. The gain in mass gives the silver deposited.

To find the time average of the current in amperes, this mass, expressed in grams, must be divided by the number of seconds during which the current has passed and by 0.001118.

In determining the constant of an instrument by this method, the current should be kept as nearly uniform as possible and the readings of the instrument observed at frequent intervals of time. These observations give a curve from which the reading corresponding to the mean

current (time-average of the current) can be found. The current, as calculated from the voltameter results, corresponds to this reading.

The current used in this experiment must be obtained from a battery and not from a dynamo, especially when the instrument to be calibrated is an electrodynamometer."

Other countries in which the silver voltameter has been legalized have adopted similar rules.[7]

3. The minute description of the form and the treatment of the silver voltameter shows clearly that a slight departure from them may result in a deposit of silver not in accordance with the definition of the ampere. It was apparent that there are in the instrument disturbing factors, which required a further study. Kahle[8] has shown that the electrolyte becomes acid by electrolysis and that on repeated use the deposits are too large.

The Reichsanstalt recommends therefore that not more than 3 grams of silver should be deposited from 100 ccm of the solution.

Leduc[9] hopes to overcome all trouble by employing a large silver anode, consisting of granulated silver. He keeps the anodic current density below 0.02 ampere/cm^2 and recommends that the amount of silver collected at the kathode should be large, say about 30 grams.

Patterson and Guthe[10] obtained concordant results by keeping the solution in contact with silver oxide. Leduc speaks in favor of this method, but Richards' results with the same type show great variations in the amount of silver deposited by the same quantity of electricity.

The greatest advance in our knowledge of the subject is due to the excellent researches of Richards[11] and his students, who showed that the main difficulty lies in the formation of a heavy anode solution, containing a complex silver ion, the existence of which had already been suggested by Rodger and Watson.[12] The anode solution which in the ordinary type of voltameter sinks to the bottom of the vessel, producing there a star-shaped figure,[13] will yield on electrolysis more silver than corresponds to the

7. *The Electrician*, vol. 27, p. 325, 1891. *Zeit. f. Instr.*, vol. 21, p. 180, 1901.

8. Kahle, *Zeit. f. Instr.*, vol. 18, pp. 229 and 267, 1898.

9. Leduc. *Journ. de Phys.*, vol. 1, p. 561, 1902.

10. Patterson and Guthe, *Phys Rev.*, vol. 7, p. 257, 1898.

11. Richards, Collins and Heimrod, *Proc.* Am. Acad., vol. 35, p. 123, 1899. Richards and Heimrod, *Proc.* Am. Acad., vol. 37, p. 415, 1902.

12. Rodger and Watson, *Phil. Trans.*, vol. 186, p. 631, 1895.

13. Behn, *Wied. Ann.*, vol. 51, p. 105, 1894.

normal ion. Besides, this substance, formed at the anode, must be a reducing agent, since oxygen tends to eliminate it. The exact chemical constitution of the substance is not known.

The main problem is to prevent the anode solution from reaching the kathode. For this purpose Richards places the silver rod, which forms the anode, in a fine grained porous cup and removes from time to time the solution collecting at the bottom.

Guthe[14] fully corroborated Richards' results, but proposed a different form of the anode. The bottom of a wide porous cup is filled with granulated silver and upon this a large silver plate is pressed. In this type the rather inconvenient frequent removal of the solution was found to be unnecessary. The heavy solution is prevented by the porous cup from rapid diffusion and breaks up to a large extent when it remains in contact with silver. This secondary reaction, he believes, gives rise to the formation of the well-known dark anode slime, which is pure silver when the anode is pure.

Other arrangements may be adopted to prevent the anode solution from reaching the kathode. The latter may for instance be suspended above the anode, or the two electrodes be placed in different vessels, connected by a siphon. From a practical point of view the latter types are however less convenient than the two described above.

4. Another source of trouble may arise from the contact of the solution with filter paper. The organic substances contained in the latter may act chemically upon neutral silver nitrate solution.[15] Filter paper should, therefore, not be used in the preparation of the electrolyte nor in the voltameter.

5. As Guthe pointed out, we can distinguish two distinct types of silver voltameters, according whether the heavy anode solution reaches the kathode or not. The former to which the ordinary type and those proposed by Patterson and Guthe and by Leduc belong will on the average yield a deposit one part in 2000 larger than the second, *i. e.*, Richards' and Guthe's types. Of course, for practical purposes, we must select the type which will give the most concordant results. As the investigations referred to show, we can rely upon the porous cup voltameter to within one part in 20,000, even for independent series of experiments; it would, there-

14. Guthe, *Phys. Rev.*, vol. 19, p. 138, 1904.
15. Reichsanstalt, *Zeit. f. Instr.*, vol. 22, p. 156, 1902.

fore, be a decided step in advance, if one of these types were substituted for the one now in common use. This would necessitate a change in the accepted value of the electro-chemical equivalent of silver, as will be shown later on.

6. Whether or not there are other disturbing factors of minor importance, only an extended research with the porous cup voltameter will show. Some of the earlier experiments are not conclusive in this respect; they were made with the usual type, and often the differences observed amount to less than what we may expect in this form of voltameter. Besides, different investigators frequently flatly contradict each other.

In the silver voltameter a neutral solution of silver nitrate is recommended. To test the neutrality it seems best to precipitate the silver by means of neutral sodium chloride solution and test the filtrate with methylorange. If the crystals contain acid it may be well to melt them in a platinum crucible.

As Kahle has shown, the solution becomes acid in being used. It is apparent that if an ion is formed containing more silver than corresponds to the normal salt, there will be some free acid left. Under such conditions the deposit will be too heavy and the acid is frequently held responsible for it. But it is different, if before electroysis free acid has been added to an originally neutral solution. In this case Leduc found the deposits one part in 5000 lighter than without the addition of acid. In fact, if the original amount of free acid surpasses a definite percentage, then on electrolysis the amount decreases. There exists a chemical equilibrium between the complex ions and those of the acid. I believe that the addition of acid to the anode side of a porous cup voltameter will be of help in either preventing the formation of the complex ion or in breaking it up.

The Reichsanstalt recommends not to use acid lest impurities of the anode pass into solution. The influence of impurities in the solution seems, however, to be of little importance, as shown by Rayleigh and Mrs. Sidgwick, who added a large proportion of copper-sulphate to the solution, and by Leduc who added copper-sulphate and also potassium nitrate. The deposits did not contain any of these impurities. It may be stated as a general rule that metals which require a higher kathodic difference of potential than silver will not be found in the deposits, if the current is not too large.

The presence of rarer metals would seem to be more serious, but they are hardly ever found in appreciable quantities in commercial silver, and, moreover, their electro-chemical equivalents are not very different from that of silver. Extreme care in the selection of material for the electrolyte as well as the anode seems, therefore, to be unnecessary. We may even use a soluble electrode of a metal, like zinc, and still obtain satisfactory results, as Richards and Heimrod proved.

7. One great objection is found in the tendency to looseness which the silver obtained from nitrate solution frequently shows. The addition of a small proportion of silver acetate improves greatly the texture of the deposit, but as was shown by Rayleigh and Mrs. Sidgwick, the deposit is always too heavy, possibly due to an inclusion of liquid. The same observers employed silver chlorate as electrolyte and obtained results closely agreeing with those given by a silver nitrate voltameter. Deposits from cyanide solution are pure white and show no tendency to looseness. Leduc[16] has made some experiments with potassium silver cyanide, but the amount of silver collected was entirely too small, which he attributed to a simultaneous development of hydrogen and silver at the kathode and to an occlusion of the former in the silver. Farup,[17] however, has shown that hydrogen is not produced, but that the silver is dissolved by potassium cyanide if air is present in the solution. He employs, therefore, a silver voltameter with potassium silver cyanide as electrolyte, but saturates the solution with hydrogen.

The results obtained by him are quite satisfactory, though I believe that with larger deposits trouble may arise due to occlusion of the liquid in the deposits. For small currents, however, this form seems to be very useful. It is claimed that even deposits from silver nitrate solution keep some of the liquid included. This will show itself in a decrease of weight when the deposit is heated to nearly red heat, the nitrate being decomposed. According to Rayleigh and Mrs. Sidgwick, there was sometimes no loss on heating, but perhaps more often a slight decrease. Kahle advises a treatment for 10 to 20 minutes with water at a temperature of 70 deg. to 90 deg. C., to insure the complete removal of the mother liquid. Richards also found a slight amount included; but Gray

16. Leduc, *Rapports* Congr. Internat. de Phys. 1900, vol. 2, p. 440.
17. Farup, *Zeit. f. Electroch.*, vol. 8, p 569, 1902

claims that with proper washing the plates may be heated without any sensible loss of weight.

8. The question of the solubility of silver in different liquids is one of great importance According to Richards and Heimrod pure silver when boiled with a silver nitrate solution will produce nitrite of silver in small quantities, but the Reichsanstalt makes the statement that this is not the case and that, therefore, under normal conditions a reduction to nitrite cannot be observed in a silver voltameter. Kahle, Myers and Merrill[18] observed a decrease of the weight of silver, when it was treated with warm water, but Richards, Collins and Heimrod, Leduc and Guthe could not detect any change when the deposit was left standing *under* water for hours.

The concentration of the silver nitrate solution seems to affect only the texture of the deposit, which has a tendency to looseness, if the solution is too weak in relation to the current. Though Gray considers it a mistake to use solutions containing more or even as much as 10 per cent of silver nitrate, all other observers deny any influence of concentration and generally recommend high concentrations, i. e., from 15 per cent to 30 per cent.

The Reichsanstalt has found that silver oxide is almost insoluble in concentrated nitrate solution, but the experiments referred to above show that solutions treated with the oxide are favorable to the formation of the complex ion and will yield too much silver.

9. Schuster and Crossley stated that the deposits of silver in vacuo were about one part in 1000 larger than those obtained from solutions surrounded by air, and these again larger than those formed in an atmosphere of oxygen. The former result was verified by Kahle, Richards and Myers.[19] The latter also found an increase when the liquid was saturated with nitrogen, but a decrease when the dissolved gas was carbon dioxide. It is reasonable to suppose that the increased weight of the deposit is due to the removal of oxygen from the solution and not to a change in pressure. In addition Merrill showed that an increase of pressure to 103 atmospheres has no appreciable effect.

Rayleigh and Mrs. Sidgwick observed an increase of deposit with increase of temperature, Leduc a decrease, Richards, Collins

18. Merrill, *Phys. Rev*., vol. 10, p 67, 1900.
19. Myers, *Wied. Ann*., vol. 55, p. 288, 1895.

and Heimrod obtained as well at 60 deg. C. as at 0 deg. C. a larger deposit than at 20 deg. C.

10. Almost all observers agree that the size of the kathode makes no difference. According to Schuster and Crossley too great a current density at the anode is accompanied by a smaller deposit; according to Leduc just the opposite is the case, while Merrill could find no measurable effect due to a variation in the size of the electrodes. Guthe's experiments lead to the conclusion that in the porous cup voltameters the size of the anode does not come into account. With the usual type of voltameter Kahle obtained a somewhat larger deposit on a silver kathode than on platinum and considers, therefore, as normal deposits such obtained on silver. Richards and Heimrod confirm this observation but find that with a porous cup voltameter no such difference appears. Guthe also obtained identical results as well when the kathode was platinum as when silver had been previously deposited on it. The explanation for Kahle's results is to be sought in the action of silver upon the heavy anode liquid, mentioned above.

The Electrochemical Equivalent of Silver.

11. The electro-chemical equivalent of silver has been determined repeatedly by absolute measurements, i. e., by means of instruments which allow a calculation of the current in terms of the fundamental units of mass, length and time. Among the earlier investigations only those of Rayleigh and Mrs. Sidgwick, and of Fr. and W. Kohlrausch can be considered accurate. In order to express all measurements in terms of the same standard, the different values found have been reduced to those given by the porous cup voltameter, and these are given in the last column of the following table. The corrections used are those found by Richards and Guthe for the various types. Since in most cases the exact conditions of the experiments are unknown, these corrected values will simply give a general idea of the agreement between different observers; therefore, it was thought unnecessary to take into account the possible effect of included mother liquid.

TABLE I.

Observer.	Year	Voltameter.	Method.	Electro-chemical equivalent	
				Found	Corrected
Mascart[1]) .. .	1884	Usual type	Current balance. ..	1.1156 mg.	1 1150 mg
Fr and W. Kohlrausch	1884	"	Tangent galv.	1 1183	1.1177
Rayleigh and Sidgwick ..	1884	" . .	Current balance . ..	1 1179	1 1175
Gray. . . .	1886	Plate voltameter.	Sine galvan . ..	1 1183	1 1177
Koepsel[2]) . .	1887	Usual type	Current balance.....	1 1174	1 1168
Pellat and Potier[3])	1890	"	" .	1 1192	1.1186
Patterson and Guthe.	1898	Silveroxide type..	Electrodynamometer	1.1192	1.1182
Pellat and Leduc[4]) . . .	1903	Leduc's type... .	Current balance . .	1.1195	1.1188
van Dijk and Kunst[5])... .	1904	Usual type	Tangent galv	1 1182	1.1176

1) Mascart, *Journ de Phys*, vol. 2, p 109, 1882 and vol 3, p 283, 1884
2) Koepsel, *Wied Ann*, vol 31, p 250, 1887.
3) Pellat and Potier, *Journ de Phys*, vol 9, p 381, 1890
4) Pellat and Leduc, *C R*, vol 136, p 1649, 1903
5) van Dijk and Kunst, *Ann d Phys*, vol 14, p 596, 1904, *Proc* Kon Ak van Wet, vol 12, p. 441, 1904

From this list we see that the results obtained so far are not very satisfactory. Redeterminations in absolute measure by using a reliable form of voltameter are highly desirable.

12. The electro-chemical equivalent of silver may also be expressed in terms of the electromotive force of a standard cell, i. e., by comparing the electromotive force of the cell with the potential difference produced by the current at the terminals of a known resistance. The electro-chemical equivalent will depend upon the value chosen for the electromotive force of the standard cell. The legalized value for the Clark cell is 1.434 volts. But this is probably too high. In Germany the electromotive force of the Clark cell is derived from silver voltametric measurements, and the Reichsanstalt has chosen as the working value 1.4328 volts at 15 deg. C. In the following table the electro-chemical equivalent of silver is calculated as well for an electromotive force $=1.434$ as for 1.433 volts.

TABLE II.

Observer	Year	Electro-chemical equivalent			
		$E = 1.434$ volts		$E = 1.433$ volts.	
		Usual type	Porous cup V.	Usual type	Porous cup V.
Carhart[1])	1882	1 1172 mg	1.1167 mg	1.1180 mg	1 1175 mg
Rayleigh and Sidgwick.	1884	1.1183	1.1178	1.1192	1 1187
von Ettinghausen[2])	1884	1.1180	1.1175	1.1188	1 1183
Glazebrook and Skinner	1892	1 1183	1.1178	1.1191	1 1186
Perot and Fabry[3])	1898	1 1193	1.1188	1.1120	1.1196
Kahle	1898	1.1173	1.1167	1.1180	1 1175
Guthe	1904	1.1174	1.1168	1.1181	1 1176

1) Carhart, *Am. Journ Sci*, vol 28, p 374, 1884.
2) Von Ettinghausen, *Zeit f Electrotechnik*, vol. 2, p 484, 1884.
3) Perot and Fabry, *Ann* Fac. des Sci. Marseille, vol. 8, p. 201, 1898.

In the case of Perot and Fabry, who used a Clark cell at 0 deg. C. and found its electromotive force to be 1.4522 volts, using 1.118 mg as the electro-chemical equivalent, the difference of 0.0164 volt given by the Reichsanstalt has been used to reduce to 15 deg. C., instead of the ratio given by them. The latter would give 1.1180 mg in the first column and corresponding values in the others, and make the agreement with the earlier experiments a very close one.

The large differences between the earlier and the more recent comparisons can hardly be due to the silver voltameter alone. Doubtless the Clark cell comes in for its share.

Wolff and Carhart and Hulett have lately discovered an electrolytic method of preparing mercurous sulphate. Cadmium standard cells, in which this substance is used, show according to preliminary reports an excellent agreement among themselves, and no variation in their electromotive force in course of time,—as far as can be ascertained during a relatively short period.

With the improvement of our standard of electromotive force and the construction of a reliable silver voltameter, a wide and interesting field for research has been opened.

Discussion.

Dr. K. E. Guthe: I can not close this paper without emphasizing one point with reference to the alleged superiority of the standard cell over the silver voltameter in the measurement of an electrical current. I still believe that the voltameter gives as accurate results as the standard cell. It must be admitted, that for laboratory use, it is easier to measure a

current by fall of potential over a resistance. And while I believe the standard cell will win out in the end, nevertheless, I am sure the silver voltameter will always be a valuable instrument for checking our work with the standard cell

Dr. R. T. GLAZEBROOK: I have already spoken a great deal at this meeting on these subjects, and do not wish to detain you very long. I am glad to have this opportunity of expressing my appreciation of the paper just read. The labor involved in producing such a paper is extreme, and its value can hardly be overestimated. I wish to particularly emphasize one point that Doctor Guthe has brought out and with which I entirely agree, and that is this, that the experiments of Mr. Skinner and myself must be held to relate solely and simply to the form of silver voltameter used by us in that experiment.

Lord Rayleigh also, I think, would disclaim the view that he had determined the electrochemistry of silver, or that he had investigated completely all the conditions that ought to be satisfied before you can say that the result arrived at was the electrochemical equivalent of silver.

In the specification for the use of the voltameter which was published by the English Board of Trade, full details are given as to the silver voltameter which he used, and which has often been used in England. It is, I think, interesting to point out our experiments as giving the ratio between the electrochemical equivalent of silver and the e.m.f. of Clark's cell. It may be the value for the electrochemical equivalent of silver derived from the experiments with the electrodynamometer needs correction, and if so that will account for the higher value of the e.m.f. of the cell, which we have always obtained in England. This is a point which I hope will be settled before very long, because, as I have already explained, an ampere balance from which we anticipate very excellent results is now under construction in England.

I will close by expressing my thanks to Doctor Guthe, and I believe that every one interested in this subject will find his work of very great importance.

Dr. W. D. BANCROFT: I should like to ask whether experiments have been made with a rotating cathode inside the porous cup. In that case there would be practically no differences of concentration in the cathode solution. You would get a better deposit, and, if necessary, you could run a higher current-density and precipitate more silver.

Dr. K. E. GUTHE: Doubtless the rotating cathode gives very satisfactory results for electrochemical analysis and it would probably be of help in silver voltametric work. The trouble with the voltameter originates, however, at the anode. One objection to a rotating electrode is the more complicated arrangement of apparatus necessitated by it.

Dr W. D. BANCROFT: The other point is apparently settled, that in the case of silver there is no difference in the weight when deposited on a platinum or a silver cathode, but that is not the case with other metals standing higher in the voltaic series. In some experiments we made on the plating of zinc, we found that in sulphate solutions there is great difficulty in getting a good deposit of zinc on a copper cathode while a zinc cathode gives satisfactory results.

Mr. S. S. Sadtler: I would like to ask Doctor Guthe whether silver nitrate would not be a good silver salt to use as electrolyte. He speaks of action on the electrodes at the surface of the electrolyte, which might be avoided by the silver salt being in a lower state of oxidation.

Dr. K. E. Guthe: In my article a number of silver salts besides the nitrate have been mentioned, but they do not seem to have proved superior to the nitrate. I am not aware that the nitrite has ever been used in a voltameter.

Doctor Bancroft then took the chair, and Doctor H. S. Carhart said:

I have only a few remarks to make on Doctor Guthe's admirable paper. In the first place, I should like to explain that the determinations I made of the e.m.f. of Clark cells at that time were incidental to some other work I was doing. I made only two determinations of e.m.f. and they could not be reduced until three years after the experiments, for the reason that the electrochemical equivalent of silver was not known with sufficient accuracy. They were not reduced until after the publication of Lord Rayleigh's paper in 1884, I think it was. This work was done in the winter of 1881 or spring of 1882, and the only Clark cell I think I had ever seen at that time was the one I used. It was a large one which was in the laboratory at Berlin. It was hermetically sealed, and in it was sealed a thermometer. The instrument itself was provided for me by Professor Helmholtz at the time. So, if I reached a fairly good value as determined by later research, it was perhaps more good fortune than the result of any very careful work.

Now, further, I must confess that I am somewhat surprised to see the wide variations and difficulties, brought out in this paper of Doctor Guthe, which occur in the use of the silver voltameter. We have been told by Professor Kohlrausch that the chemical reactions or relations in the silver voltameter are much simpler than they are in the standard cell; but after reading this paper, I think that statement is very doubtful. It strikes me there are many more points left unsettled in the use of the silver voltameter than there are in the standard cell. At all events, the discrepancies now are at least as great as we find in standard cells, and I believe that the discrepancies with the silver voltameter are greater than those in standard cells. But it must be admitted by everybody that when we are going to measure currents we can not use the silver voltameter, but must use standard resistances and a standard cell with a potentiometer.

I wish to add one more remark with reference to the difference in the e.m.f. of the Clark cell obtained by the silver voltameter at the Reichsanstalt and elsewhere. It is not generally known that the value obtained by means of the silver voltameter at the Reichsanstalt was corrected by reference to the ratio between the e.m.f. of the Clark cell and that of the cadmium cell measured by a direct comparison, and this fact accounts for a part of the difference. The procedure was as follows: The e.m.f. of the Clark cell at 15 deg. was determined by the silver voltameter, or at least the results were corrected to 15 deg. The e.m.f. of the cadmium cell at 20 deg. was also measured by the silver voltameter; and thus the ratio between the Clark cell at 15 deg. and the cadmium cell at 20 deg.

was obtained. This ratio has also been determined by direct comparisons, and several series of such comparisons have been carried out. The inference then was that the directly measured ratio of Clark 15 deg. to the cadmium 20 deg. was more reliable than that obtained by the use of the silver voltameter. The ratio obtained by the silver voltameter was then corrected The value of the e.m.f of the Clark was reduced, and that of the cadmium cell raised, in order to make the ratio correspond to that obtained by direct measurement The reduction in the cadmium cell and the increase in the Clark was of course small. That correction accounts for a part of the difference in results.

The following paper was then read by Professor Carhart.

A STUDY OF THE MATERIALS USED IN STANDARD CELLS AND THEIR PREPARATION.*

BY PROF. H. S. CARHART AND PROF. GEO. A. HULETT.

PART I.

MERCUROUS SULPHATE AND STANDARD CELLS.

BY GEO. A. HULETT, *Assistant Professor, University of Michigan.*

Variations in the e.m.f. of standard cells have been traced to the Hg_2SO_4 used as depolarizer, and especially Jaeger and St. Lindeck, Zeitsch. f. Instk. 21, 33, 1901, have shown that cells made with mercurous sulphate from different sources may differ as much as 0.0002 *V*. It is also well known that standard cells, when first set up, have a high e.m.f., but in a month or so settle down to a constant value. Also little is known of changes taking place when Hg_2SO_4 is exposed to the light.

In conjunction with the work of Professors Carhart and Patterson on the absolute determination of the e.m.f. of the cadmium cell, the chemical side of the cell has been taken up and the following results obtained.

The preliminary work was the testing of various samples of Hg_2SO_4 from the point of view of their use as a depolarizer. In each leg of an *H* cell was placed mercury and the cell was then filled to above the cross-bar with dilute H_2SO_4; with mercurous sulphate on the mercury there was no e.m.f. provided the Hg_2SO_4 in each leg was from the same sample, but different samples generally gave an e.m.f. One preparation (electrolytic, to be described later) was taken as a standard and all others compared to this reference Hg_2SO_4.

Preparations of well-known makes differed markedly often by 0.001 *V* when tested in this way, and my own preparations made in various ways showed little agreement. That prepared by *adding* a solution of $HgNO_3$ slowly *to* H_2SO_4 (1 to 6 vol.) with rapid

* This investigation, carried out with the aid of a grant from the Elizabeth Thompson Science Fund, is still in progress. The authors desire to express their indebtedness to the trustees of this fund.

stirring seemed best, that is, it was practically the same as the electrolytic, while the sample made by adding $HgNO_3$ to $CdSO_4$ solution showed +.0002 *V*. These results led me to devise the following electrolytic method of preparing pure Hg_2SO_4. It seemed desirable to use only Hg and H_2SO_4, but these substances interact with sufficient rapidity only when concentrated H_2SO_4 is used and at a high temperature; also this product carries H_2SO_4 which is difficult to remove, and gives a high e. m. f. in a single potential electrode, as shown by Sauer, *Zeitsch. Ph. Ch.* 47, 182, 1904.

The desire to use dilute H_2SO_4 at a low temperature suggested the idea of using an electric current and making the mercury the anode with a Pt. kathode in the dilute H_2SO_4. Ostwald, *Zeitsch.*

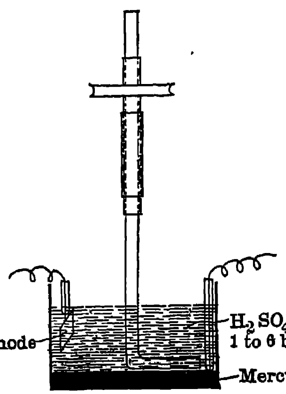

FIG. 1.

Ph. Ch. 15, 500 (1895), and Nernst, *Zeitsch. Ph. Ch.* 34, 129, have shown that Hg under such conditions goes into solution as mercurous mercury, and in our case H_2 is separated on the Pt. kathode; later when the electrolyte contains mercurous ions some of these are also deposited on the Pt. but due to the slight solubility of Hg_2SO_4 (0.400 *gm/L.*) and the large excess of *H* ions, relatively little mercury is deposited on the kathode.

As soon as the electrolyte becomes saturated with Hg_2SO_4 the salt begins to separate in a crystalline form and collect on the mercury. A motor-driven stirrer is needed to keep the surface of the mercury free of Hg_2SO_4 and in contact with the electrolyte. Fig. 1 gives a sectional view of the apparatus needed to prepare the electrolytic mercurous sulphate.

In the bottom of a strong beaker glass or dish is placed mercury

1 to 2 cm deep and on this is sulphuric acid (1 to 6 by volume) some 10 cm deep. A Pt. electrode of convenient size is suspended in the acid, while contact is made with the mercury in the usual way with a Pt. wire, protected, except at its point, with a glass tube. One may use a current density of 0.3 amp. to 100 cm^2 mercury surface or even more when all is working nicely. The stirring is important, the *L* part of the stirrer should pass close to the surface of the mercury and quite rapidly, but not so rapidly that the surface of the mercury will be broken into globules. The stirrer is best provided with metal bearings that do not abrade. If not sure of the purity of the mercury it is best to remove it after running a few hours and start afresh. The mercury is easily and neatly removed by a separatory funnel.

One hundred cm^2 mercury surface should yield about 3 gm per hour, and it is well to prepare the Hg_2SO_4 in a dark room or out of bright light, as light decomposes the sulphate. If too strong acid is used or the stirring is too rapid the product will be quite grey, due to finely divided mercury, but with continued and steady agitation with mercury and acid the Hg_2SO_4 becomes white, crystalline and fairly large grained.

The sulphate should be preserved in contact with mercury and under acid (1 to 6 vol.) in the dark until needed. Analysis has been made of this product showing it to be Hg_2SO_4, while its behavior in the standard cells shows that it is a very pure product, and it will be seen later that it does not contain a trace of $HgSO_4$ (ic) although there is a little mercuric mercury in the solution from which it is separated.

Cells made up with this electrolytic Hg_2SO_4 as depolarizer,—provided precautions are taken to avoid hydrolysis — show a much better agreement than has hitherto been obtained in standard cell work. This is shown by the measurements on cells (D_1 to D_4) and (F_1 to F_{10}) by Professor Carhart, as given in this paper, the e.m.f. at 21.1 deg. being 1.01908 int. volts for the cadmium element, a value that is 0.00030 *V* lower than cells constructed according to the old method.

We have based our method of constructing the cells on the facts brought out in the following study of the equilibrium in the positive leg of the cadmium cell and of the hydrolysis of mercurous sulphate.

Abel, *Zeitsch. Anorg, Chem.* 26, 361 (1901), has shown that whenever we have mercury in contact with a solution containing

a mercury salt there will result an equilibrium between the (ous) and the (ic) mercury in solution and the metal. For the nitrate Abel found the ratio of $\frac{Hg\ (ous)}{Hg\ (ic)} = 200$. There is relatively little (ic) mercury in a solution that is in equilibrium with mercury; and since the mercuric sulphate is more soluble than the mercurous, if we bring the system Hg-Salt-solution to equilibrium, the salt cannot contain mercuric sulphate, but would be only mercurous sulphate. To test this point some mercuric sulphate was recrystallized from dilute H_2SO_4. The mass soon became grey, due to finely divided mercury, but on continued agitation, the salt became white and beautifully crystalline. A cell was made up from this salt and showed at 21.1 deg. 1.01911 volts, a value practically identical with the electrolytic Hg_2SO_4, a result that substantiates the conclusions drawn from Luther and Abel's work.

In the positive leg of the cadmium cell we have Hg, Hg_2SO_4 and $CdSO_4\ \frac{8}{3}\ H_2O$ in contact with a saturated solution and we are then to conclude that here also the solution will contain both mercurous and mercuric mercury, while the solid salt is only Hg_2SO_4 and possibly a basic salt.

A solution that was brought to equilibrium with Hg, Hg_2SO_4 and $CdSO_4\ \frac{8}{3} H_2O$ at 25 deg. was carefully analysed by adding a little KCl which precipitated the mercurous mercury as HgCl. It was found that a liter of such a solution contained 1.090 gm of mercurous mercury, a surprisingly large amount in view of the solubility of Hg_2SO_4 in dilute sulphuric acid, 0.400 gm/L.

It has been further shown by Abel l. c. that in the absence of the metal we may remove the mercurous mercury and not disturb the mercuric mercury; so the filtrate from the above determination contained all the mercuric mercury originally present; and if now we bring this filtrate again in contact with metallic mercury the old equilibrium ratio will be established; and, since a slight excess of KCl is present, the (ous) mercury will separate as fast as formed. Thus mercuric mercury may be detected and determined.

It was found that on bringing the above-mentioned filtrate into contact with mercury HgCl began to form at once and collect as a coat on the mercury. The amount is small and difficult to determine quantitatively. One result indicated the ratio of $\frac{Hg\ (ous)}{Hg\ (ic)}$ = about 80 for the cadmium sulphate solution.

Theoretically, it should make no difference whether we construct a cell with mercurous or mercuric sulphate; the final equilibrium would be the same in either case; but the conditions in a cell are very unfavorable to attaining equilibrium; and, mercuric sulphate being more soluble, would increase the total e.m.f. of the cell.

THE HYDROLYSIS OF MERCUROUS SULPHATE.

Mercurous salts on dissolving yield some mercuric mercury and metal and tend to come to an equilibrium as indicated above; therefore it was deemed advisable always to keep an excess of mercury present when working with mercurous sulphate. Accordingly some 15 grams Hg_2SO_4 with a large excess of Hg was shaken with 400 c. c. of water at 25 deg. until equilibrium was established. The salt remained white, that is, the yellow salt commonly observed did not appear. The solution contained 0.00235 moles of mercurous mercury per liter and 0.00225 moles SO_4 and showed a conductivity of 0.000975 ohm^{-1} cm^{-1} at 25 deg. The solution was syphoned from the solid and 400 c. c. more water added and again shaken and this process repeated, waiting each time until equilibrium was obtained. The conductivity of the successive portions remained the same 0.000975; also analysis showed the composition of these successive solutions to be constant. The residue did not turn yellow, but did in time take on a greyish tinge. Evidently the commonly-observed yellow salt has little to do with the hydrolysis of mercurous sulphate. The 22d solution was like the preceding, but the 23d showed a marked drop in the conductivity, while the succeeding portions now had a conductivity of only 0.000060, and analysis showed a correspondingly small amount of mercury present, only 0.037 mg mercurous mercury in a liter.

Evidently the mercurous sulphate had completely disappeared and the residue (8.5 grams) was the completely hydrolysed product. It was greyish white and crystalline. Analysis showed 84.30 per cent of mercury and 10.50 per cent of SO_4. These percentages do not show a close agreement with the formula given by Gouy (Cr. 130, 1399, 1900) $(HgOH)_2\ Hg_2SO_4$, which requires 86.02 per cent Hg and 10.32 per cent SO_4. However, it was found that the basic salt does not dissolve as such, but is decomposed by the continued action of water[1], and the above salt had been in contact with much water after forming. The results, therefore, confirm

1. Compare Cox, "Ueber basische Quecksilbersalze," *Zeit. Anorg. Ch.*, 40, 146, 1904.

Gouy's formula; and further, since the solution contained uniformly 0.00235 eq. ous mercury to 0.0022 of SO_4, there must be $HgHSO_4$ in solution, the slight excess of mercury over SO_4, coming from the slight solubility of the basic salt. We are to conclude then that a solution of 0.0023 moles of $HgHSO_4/L$ will not hydrolyse mercurous sulphate, and might safely be used in a preliminary washing of the sulphate.

From the above, then, the hydrolysis of Hg_2SO_4 takes place as follows:

$$3Hg_2SO_4 + 2H_2O = (HgOH)_2Hg_2SO_4 + 2HgHSO_4.$$

And further, a liter of water hydrolyses 1.75 gm Hg_2SO_4 leaving 0.90 gm of $(Hg_2OH)_2\ Hg_2SO_4$ as a residue while 0.68 gm $HgHSO_4$ go into solution.

It seemed further advisable to know the concentration of sulphuric acid which would prevent the hydrolysis of Hg_2SO_4 and this information was sought by following the solubility at 25 deg. of Hg_2SO_4 in H_2SO_4 of varying concentrations. Here again mercury was always present in excess and care was taken that the system Hg, Hg_2SO_4 solution was really in equilibrium before analysis was made of the liquid phase. The following table gives the results obtained, the mercurous mercury in 200 c. c. was in each case weighed as HgCl, and in all cases the filtrate showed a brown coloration with H_2S. Here again we find the equilibrium between Hg and (ous) and (ic) mercury in solution. The ratio in these cases was $\frac{Hg\ (ous)}{Hg\ (ic)} = 200.$

Dilution of H_2SO_4	Grms of HgCl /200 c c.	Moles of Hg(ous) /L	Grms. of Hg(ous) /L.
250 L.	.0886	.001880	.376
100	.0755	.001603	.321
50	.0719	.001527	.305
20	.0726	.001537	.307
10	.0768	.001625	.325
5	.0827	.001762	.352
4	.0860	.001826	.365
3	.0925	.001962	.392
2	.0983	.002081	.416
1	.1034	.002208	.442
$\frac{3}{4}$	.1022	.002121	.424
$\frac{1}{2}$	.0908	.001932	.386
$\frac{1}{4}$	.0411	.000871	.174

The results plotted in the form of a curve with concentrations of mercurous mercury as ordinates and dilution of H_2SO_4 (number of liters which contain a molecular weight) as abscissa show the peculiar behavior of the salt. Starting with the most concentrated acid H_2SO_4 ($V = 1/4L$) (eight times normal) the solubility is very small, 0.174 gm of (ous) mercury in a liter, but the solubility increases rapidly with dilution of the acid and is a maximum at H_2SO_4 $V = 1L$. Here there is a sharp break in the curve, the solubility decreases rapidly with dilution and linear from ($H_2SO_4 V = 1L$) to ($V = 4L$) where another less marked break

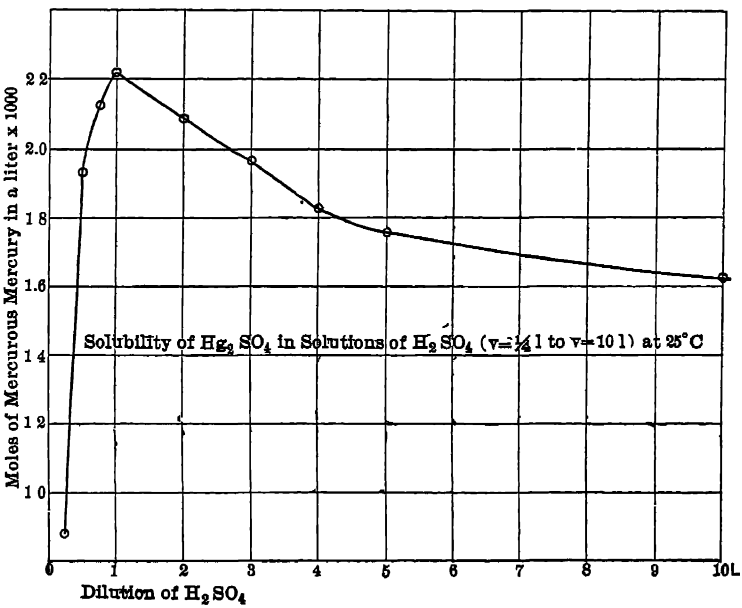

FIG. 2.

occurs. From $V = 4L$ the decrease in concentration of (ous) mercury is less rapid, becomes a minimum at $V = 40L$ and then begins to increase to 0.371 gm of (ous) mercury in a liter at $V = 250L$.

The cause of the interesting break at H_2SO_4 $V = 1L$ has not yet been fully ascertained, but at H_2SO_4 $V = 4L$ hydrolysis has already begun to be effective, yielding $HgHSO_4$ in solution and this acts against the decreasing solubility, and at H_2SO_4 $V = 40L$ actually reverses the direction of the curve.

It was deemed advisable to prepare Hg_2SO_4 electrolytically from H_2SO_4 of greater strength than ($V = 1L$) and a sample was made from H_2SO_4 $V = 1/3L$ and washed with alcohol to remove the acid and water and then analysed. The result was 80.50 per cent Hg and 19.40 per cent of SO_4 (theory requires 80.65 per cent mercury and 19.36 per cent SO_4). A second sample of Hg_2SO_4 was made from acid of a strength falling between $V = 1L$ and $V = 4L$, that is on the straight line beyond the break at H_2SO_4 $V = 1L$. Analysis of this sample showed 80.77 per cent Hg and 19.25 per cent SO_4 indicating the presence of a very small amount of basic salt.

Cadmium cells were now made up with these two samples and the one made from the last sample ($V = 2L$) gave the higher e.m.f. by 0.0001 V, indicating the presence of basic salt.

Hg_2SO_4 should, therefore, be made from acid stronger than H_2SO_4 $V = 1L$ and the strength first chosen by chance 1 to 6 by volume, about H_2SO_4 $V = 1/3L$, seems to be about right.

A cadmium cell was now made up in the usual way only the depolarizer was the completely hydrolysed salt and the e.m.f. is only 1.01620 V after two months and it has not yet reached its constant value. This result agrees with the slight solubility found for the hydrolysed salt assuming it is also less soluble in $CdSO_4$ solution than Hg_2SO_4. It is to be noticed that the greater the concentration of mercury in the solution of positive leg of the cell the greater the total e.m.f. and *vice versa,* for solutions of mercury are decidedly negative to the metal mercury; e. g., in the single potential calomel electrode the solution contains 0.030 gm Hg/L only, but the potential difference is 0.560 V. Above we have found that a saturated Cd_2SO_4 solution dissolves about 1.1 gm to a liter of (ous) mercury and it seemed probable that the e.m.f. in the positive leg would be quite large. This was tested by a calomel electrode which was joined to a cadmium cell and it was found that the potential difference between the cadmium amalgam and $CdSO_4$ solution was only 0.0862 V, while in the positive leg the potential difference was 0.934 V, a surprising result, but in accord with the solubility of Hg_2SO_4 in a saturated $CdSO_4$ solution. In the determination of the single potential differences no account was taken of the potential difference at the junction of the KCl/n solution of the calomel electrode and the $CdSO_4$ solution of the cell, as the necessary data for calculation is not at hand; but it is known that such potential differences are small.

The above results emphasize the importance of the role played by the depolarizer Hg_2SO_4 on the e. m. f. of standard cells. Further indirect evidence on this point was obtained by the following cadmium cells I_9 and I_{10} set up in the usual way except in I_9 the solution used to fill the cell contained some $ZnSO_4$ (1 part $ZnSO_4$ to 99 parts $CdSO_4$) and in cell I_{10} the amalgam contained zinc (1 part to 99 Cd). I_9 has the same value as another cell made with same materials, but without $ZnSO_4$, indicating that $ZnSO_4$ — the most probable impurity to be expected in the $CdSO_4$ — is not to be feared. The cell I_{10} showed an e. m. f. 0.00013 V higher than I_9, that is, the 1 per cent Zn affected the e.m.f. by .00013 V only; and in time I_{10} will no doubt agree with I_9 since Zn will go into solution and deposit Cd.

A cell was now set up with electrolytic Hg_2SO_4 washed to avoid hydrolysis, but then mixed with about one-sixth its weight of the completely hydrolysed salt. The cell had the value 1.01939 V 21.1 deg. at first and is now, after a month, 1,01934. This indicates that a mixture of Hg_2SO_4 and $(Hg_2OH)_2\ Hg_2SO_4$ gives a higher e.m.f. than either alone, that is, yields a greater concentration of mercury in the solution in the positive leg of the cell. If precautions are taken to prevent hydrolysis we have only Hg_2SO_4 present, and the cadmium cell has the value 1.01908 int. volts at 21.1 deg.

With proper precautions in the preparation and washing of the Hg_2SO_4 the cadmium cells seem to be reproducible to at least five parts in 100,000 and it seems probable that more experience will even reduce this variation. The important point is the rigid exclusion of the hydrolysed product either in the preparation or washing of the Hg_2SO_4. The directions given in the second part embody the results of our work and experiences to date, and it might be added that the washing with absolute alcohol and ether to remove the acid has many points in its favor; but for some reason the cells so constructed are at first some 0.00010 V high and only attain the normal value in a month or so, but do not finally differ from those made by washing with $CdSO_4$ solution. The Hg_2SO_4 prepared as directed is distinctly crystalline and the grains of sufficient size to avoid any effect of size of particles on the solubility. The details of the analyses and experimental work given in this paper appeared in full in the *Zeitsch. f. Ph. Ch.* 49, 483 (1904).

PART II.

PREPARATION OF MATERIALS AND CONSTRUCTION OF CELLS.

BY PROF. HENRY S. CARHART, *University of Michigan.*

The chemical research done on mercurous sulphate by Dr. Hulett points out the best method, according to present information, for preparing this salt for use in Clark and Weston standard cells. The present part of this paper will be restricted to directions for preparing the materials entering into standard cells, particularly the Weston Normal Cell, with excess of cadmium sulphate crystals, to the method of setting up cells, and to the results of observations extending over a period of more than a year.

MERCURY.

The mercury for the positive electrode and for making the mercurous sulphate should first be thoroughly shaken with a dilute nitric acid solution of mercurous nitrate;[1] and, after drying, it should be distilled in a vacuum at least twice.

CADMIUM SULPHATE.

Chemically pure commerical $CdSO_4\ 8/3H_2O$ is dissolved at room temperature in its own weight of distilled water, preferably with the aid of a motor-driven stirrer. The solution must be filtered till it is perfectly clear; it may then be placed in a large crystallizing dish in a small room free from dust. It is advantageous to remove the water vapor by appropriate drying agents. The slow crystallization taking place should insure perfectly transparent crystals.

After about two-thirds of the water has evaporated the mother liquor should be poured off and *only the clear crystals should be selected.* Those that are white may be redissolved and added to the mother liquor. The solution is again filtered clear and is left to crystallize as before. The selected clear crystals are rinsed with

1. *Zeit. Ph. Ch.*, 33, 611.

distilled water, drained, and left to dry; or they may be dried by spreading them out on sheets of filter paper.

In crystallizing about five kilogrammes of $CdSO_4$ 8/3 H_2O the final 100 c. c. of mother liquor contained only the merest trace of zinc; and zinc is the chief impurity to be eliminated. It should remain in the mother liquor, since zinc sulphate and cadmium sulphate are not isomorphous.

Moreover, a trace of zinc sulphate mixed with cadmium sulphate produces only an insignificant effect on the e.m.f. of the cell. Cell 19 was made up with a solution containing 1 per cent zinc sulphate and 99 per cent cadmium sulphate. Its e.m.f. is not higher than that of other cells made at the same time and not containing zinc sulphate.

Cadmium sulphate crystals dissolve very slowly. The solubility is increased by heat, but the temperature must not be raised above 40 deg., in order to avoid the formation of a different hydrate. The crystals should be covered with two-thirds their weight of distilled water in an Erlenmeyer flask. A suitable stirrer should keep the water moving over the crystals for at least half a day, preferably in a bath at 25 deg. controlled by a thermostat. The solution should be clear and should remain so. It should be left standing over the crystals, and when it is used it should be saturated at a temperature as high as 25 deg. The saturation of the solution is of great importance in order that the cells may quickly reach electrical equibibrium.

Cadmium Amalgam.

The cadmium amalgam invariably used in all the cells under observation contained 12.5 per cent metallic cadmium. To prepare it the following method is recommended: A large crystallizing dish is nearly filled with a saturated solution of cadmium sulphate slightly acidulated with sulphuric acid. In a small, low crystallizing dish is placed a weighed quantity of pure mercury, and the dish with its mercury is immersed in the acidulated cadmium sulphate solution. The pure cadmium of commerce is melted down into a large flat button with a stick of cadmium attached for electrical connection; or, several of the cadmium rods, bound together, are placed together in a vertical position with their lower ends in the solution and beneath them a small crystallizing dish. If the cadmium button or disk is used, it should be placed in the second low crystallizing dish, which retains the finely divided

anode powder. The metallic cadmium is then made the anode and the mercury the kathode, connection with the latter being made by means of a platinum wire sealed, except at its end, in a glass tube. The fall of potential from anode to kathode should not exceed 0.3 volt. An ammeter should be used to keep account of the quantity of electricity flowing through the cell, until something more than the requisite weight of cadmium has been deposited on the mercury kathode. The small dish containing the cadmium amalgam is then removed from the bath and warmed till the amalgam melts under the cadmium sulphate solution. When cool it forms a beautiful crystalline disk. The solid amalgam should then be washed, dried on filter paper, and weighed. The necessary additional weight of mercury to make a 12.5 per cent amalgam is finally added. It may be kept under cadmium sulphate solution, and should be melted on a water bath to insure homogeneity before using in a cell. This method yields an amalgam free from zinc, and there is no oxide or dross formed, as there is when the amalgam is made by the method of heating the weighed cadmium and mercury.

Mercurous Sulphate.

Recently, both in this country and in Europe, variations in the electromotive force of standard cells have been traced to the mercurous sulphate. The method in use by the European manufacturers of this salt consists in its precipitation by bringing together a solution of mercurous nitrate and sodium sulphate or sulphuric acid. This method does not insure the absence of all nitrate, and when sodium sulphate is used hydrolysis of the precipitated salt takes place. The following standard method has, therefore, been devised by Dr. Hulett:—

In a flat-bottomed glass vessel is placed pure mercury about 2 cms deep. It is covered with dilute sulphuric acid to a depth of 8 or 10 cms. The acid is prepared by adding one part by volume of concentrated H_2SO_4 to six parts of distilled water. Hydrolysis of mercurous sulphate does not take place in the sulphuric acid solution of this concentration. The solution is electrolyzed by making the mercury the *anode* and a piece of sheet platinum hung in the acid the kathode. A current density of about 0.5 ampere per 100 cm^2 surface of mercury may be employed. As soon as the current begins to flow a crystalline mercurous sulphate forms. A stirrer, consisting of a glass rod bent at right angles

at the bottom, must be used to keep the surface of the mercury exposed and to stir the solution and the salt formed; it should be driven rapidly by a motor. A little over 4 grammes an hour can be prepared in this way with a current of half an ampere. The apparatus should be kept covered with black paper or black cloth, since mercurous sulphate darkened by exposure to light gives too high an e.m.f. If the stirring is continued after the circuit is broken, the crystals of mercurous sulphate increase in size and become whiter.

The mercurous sulphate may be removed from the mercury by means of a separatory funnel, but it should be kept under the 1 to 6 acid solution, in contact with mercury, and in the dark.

The Paste.

When ready to fill cells, the mercurous sulphate must first be washed free from sulphuric acid. For this purpose a small Gooch crucible of about 25 c. c. capacity is filled three-fourths full of the salt, avoiding much free mercury which interferes with the filtering. A tiny filter paper covers the perforations in the bottom of the crucible; the whole is mounted on a Bunsen filter flask and the latter is attached to a filter pump.

The mercurous sulphate is first washed a couple of times with the (1 to 6) dilute sulphuric acid, and then five or six times with saturated cadmium sulphate solution to remove the acid; only a few cubic centimetres of the solution are needed for a single washing; after each washing the liquid is to be removed as completely as possible by the filter pump. The last washing leaves the mercurous sulphate ready to be made into a paste. It is advisable to remove the top layer after the last washing.

An alternative method is to wash with absolute alcohol instead of the cadmium sulphate solution, and finally once with sulphuric ether.

The paste is then made in a clean agate mortar by grinding together crystals of the pure cadmium sulphate and a little mercury, and then mixing in about three volumes of the washed mercurous sulphate; finally, add enough saturated cadmium sulphate solution to make a thin paste.

Setting up the Cell.

The *H*-form of cell is altogether the most convenient to make and to fill. Fig. 3 shows the glass cell, ready to

be filled. The tubing is drawn out at *a* so as to leave the diameter about 6 mm and with thin walls at this point. The amalgam is melted over a water bath and is introduced by means of a small tube, slightly contracted at the end, and of a diameter that will allow it to pass freely through the neck at *a*. The warmed tube is used as a pipette, and it permits of introducing the amalgam quickly and without splashing. It should always be wiped with a filter paper or clean cloth before it is introduced into the cell.

The mercury, the thin paste, and the concentrated cadmium sulphate solution may be introduced in the same manner. An

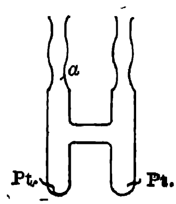

FIG. 3.

alternative method is to fill the cell through little funnels, made by drawing out small test tubes. They must pass through the neck at *a*, and reach well down toward the bottom. After the mercury, the amalgam and the paste have been introduced, both legs of the cell are filled with clean, dry, transparent crystals of cadmium sulphate. Enough of the saturated cadmium sulphate solution is finally added to fill the cell to the top of the cross-connecting tube.

The cell is finally sealed off at the point *a* by means of two small horizontal blast flames, 5 cm long, directed in a line toward each other and just meeting. The narrow part *a* is brought between the impinging flames, the glass quickly softens, and the top part is drawn off. A cell sealed in this way contains nothing but the necessary materials of the voltaic combination. It cannot leak, and can be immersed in a kerosene bath without danger that the oil will penetrate into the inside, as it does when the cell is sealed with paraffin and sealing wax.

RESULTS.

The two curves in Fig. 4 show the behavior of two cells, *D*1 and *D*6, for 40 days after they were placed in a constant temperature bath at 21.1 deg. The lower curve belongs to *D*1 and the upper one to *D*6. *D*6 was made with mercurous sulphate pre-

pared by precipitation with a solution of cadmium sulphate; $D1$ was made with the same materials, except that the electrolytic mercurous sulphate was used. The e.m.f.'s are in international volts.

More than 100 cells in all have been set up to test the various methods of preparing the materials, chiefly of the mercurous sulphate. Many thousands of comparisons have been made. I have

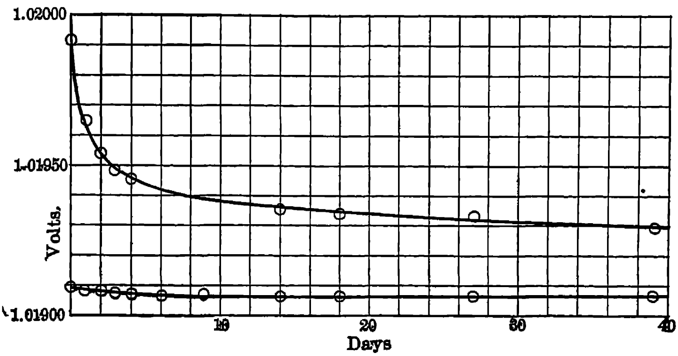

FIG. 4.

selected for the following tables only such as seem to be most valuable from the point of view of the results attained. The comparisons have all been made by means of a potentiometer made by Wolff of Berlin and an H-pattern galvanometer made by the Leeds & Northrup Company of Philadelphia. It is quite easy with this outfit to read to the fifth decimal place. The temperatures were taken with a Haak thermometer, graduated to hundredths and accompanied by a Reichsanstalt certificate.

One cell of Series B, set up in June, 1903, has been used as a reference cell for setting the potentiometer. Six of these B cells, set up in the same manner, are in very close agreement. Assuming the ratio Clark 15 deg./Cadmium 20 deg.= 1.40670, the Weston Normal Cell at 21.1 deg., set up with mercurous sulphate made in the old way, would have an e.m.f. of 1.01936 international volts. The values given in the tables are international volts on this basis. All measurements were made with the cells in a kerosene bath; and in every case the temperature was controlled by a thermostat, except for the temperature of 1.7 deg., July 9.

Cells $D1$ to $D4$ were set up Dec. 21, 1903; $F1$ to $F10$, Feb. 15, 1904, the J cells and the K cells at the date of the first measurements recorded under them.

Date	D cells.				Date	F cells									
	1	2	3	4		1	2	3	4	5	6	7	8	9	10
°					°										
Jan 5, 21 0	1 01909	1 01910	1 01910	1 01910	Feb 15, 21 1	1 01907	1 01907	1 01007	1 01908	1 01908	1 019065	1 01907	1 01908	1 01905	1 01907
6, 21.1	08	09	09	09	16, 21 1	065	06	07	08	07	06	06	07	07	065
7, 21.1	08	08	085	09	17, 21 1	07	07	07	07+	07	06	075	075	07	07
9, 21.1	07	08	08	08	20, 21 1	07	07+	075	08	08	08	075	07	08	075
11, 21 1	07+	07	07	08	25, 21 0	08	08	08	08	085	085	08	08	09	08
14, 21 1	07	06	07	075	Mar 1, 21 1	08	08	08	08+	08	08	08	08	08+	08
19, 21 1	06	065	07	07+	4, 21 2	08	08+	08+	08+	08	08	08	08	08	08—
23, 21 1	06	06	07	07	12, 21 0	075	08	08	08+	08	08	08	075	08	08
Feb 1, 21.1	065	065	07	075	17, 21 3	075	08	08	08	08	08	08	08	08	08
13, 21 1	07	08	08	085	21, 21 3	07	07+	08	075	07+	07	07+	07+	08—	08
16, 21.1	07	08	08	08	28, 21.0	075	08	08	085	08	075	075	08	08	
18, 21.1	07	07	08	08+	Apr 2, 21 2	07	07+	08	08	08	075	08	08	08+	
22, 21.2	07	08+	09	09	9, 21 0	08	08	085	08	09	08	08+	08	08+	.
25, 21.2	07	08+	085	09	16, 21.0	08	085	085	08+	085	07	08	08	085	
Mar 1, 21.1	07	07	075	08	28, 21 1	07	075	08	08	08+	08	08	08	08	. .
5, 21 2	07	07	075	08	May 13, 21 12	08	085	08	09	09	085	09	09	085	
12, 21.1	07	07	07	07+	June 13, 21 16	07	08	08	08	085	08	085	08		. .
15, 21.1	07	07+	07	075	July 9, 1.7	46	51	51	51	52	51	55	51	51	....
17, 21 0	06	065	07	07+	12, 21 08	08	09	085	09	09	09	085	09	09	.
Aug. 1, 21.1	05	07	08	08	Aug. 1, 21 08	07	08	08	08	085	08	09	085	085	... ..

Date and temperature	J cells 3	J cells 5	J cells 9	J cells 10	Date and temperature	K cells 1	K cells 2	K cells 3	K cells 5	K cells 6	K cells 9	K cells 10
May 13, 21.10°	1.01919	1.01910	....	....								
24, 21.05	18	085	. ...	....								
June 6, 21.15	16	11	. .	.. .	June 25, 21.10°	1 01919	1 01920	. .. . ..	.. ..	. .	. .	... .. .
18, 21.16	09	06	.. ..	... . .	28, 21 08	16	16	1 01916	... . .	.,	. .	..
25, 21.10	07	065	1 01914	1.01916	30, 21.00	16	16	15	....	.	. . .	... ..
28, 21 08	07	06	13	14	July 11, 21 15	14	14	13	1.01917	1.01913	1.01918	1.01918
30, 21.00	08	08	14	14	12, 21.07	15	15	15	18	15	17	18
July 27, 21.00	08	09	11	12	27, 21.00	13	14	12	15	14	13	14
August 1, 21 08	06	08	12	12	August 1, 21.08	13	13	13	15	14	13	14

All these cells have been kept for the most part in a bath at about 21 deg.; but the *D* and the *F* series were placed in a bath near 1.5 deg. for 48 hours, or until their e.m.f. had apparently reached a stable value for this temperature. The e.m.f. for the *F* cells at 1.7 deg. are shown in the table under July 9. The *D* cells reached a maximum mean of 1.019625, as compared with 1.01951 for the *F* series. The mean temperature coefficient for all of them for this range of 19.4 deg. is in close agreement with the Reichsanstalt formula.

Of the *J* cells, 3 and 5 contain mercurous sulphate washed with alcohol; 9 and 10 were washed with the $CdSO_4$ solution. All of them are apparently coming down to the level of the *D* and *F* series.

Of the *K* group, 1 and 2 were set up with mercurous sulphate washed with $CdSO_4$ solution; 3, 5 and 6 with alcohol. Cells 9 and 10 were set up with mercurous sulphate prepared with great care by letting mercurous nitrate solution drop, with constant stirring, into a strong solution of sulphuric acid (one gm molecule to a half litre of water). These cells are identical in value with 5 and 6, and they show that it is possible to make mercurous sulphate by precipitation with a strong solution of acid without appreciable hydrolysis, if the proper skill and precautions are applied. But the electrolytic method of preparing Hg_2SO_4 is far easier and the product is much more uniform.

All these *J* and *K* cells exhibit a slow subsidence to their final value. The *D* and *F* series attained their electrical equilibrium very quickly. In fact the first measurements on the *F* cells were made within three hours after they were filled, and they had already attained the values which they have maintained for the past six months.

Discussion.

Doctor R. T. Glazebrook: I think that we all agree that Professor Carhart has advanced very greatly our knowledge of the properties of standard cells by this important piece of work. Similar observations, though not so complete, have been going on for some time in my own laboratory, and we have arrived at very much the same results. For example, we find, as Lord Rayleigh found, that the mercurous sulphate is the chief source of difficulty, and that was made clear in a paper which was read before the British Association a fortnight ago. I there described three methods of preparation, one being that of Professor Carhart, which lead to practically identical results. Without burdening the meeting further with details, I may say that in the results which I have

here for nine cells, prepared by these different methods, expressed in terms of one standard cell, in the same way as in that table, Series F, the numbers that correspond to the numbers given by Professor Carhart would vary between 20 and 21, when expressed in hundredths of a millivolt.

I think it is of importance to observe, as I have stated, that we have reached this result by means of three different methods. Which method may prove to be the most easy in practice or most satisfactory, I am hardly prepared to say at present. I would like to emphasize a point Professor Carhart has made, and which we have found to be the case. It is very necessary to stir well, in using the electrolytic method. We use a rather higher current-density than Professor Carhart recommends. We hope to go on, as I have already stated, as soon as I return, with comparisons between these cells and the electrochemical equivalent of silver. But I have brought with me here to St. Louis six cells prepared in accordance with the three formulas named, and Professor Stratton has promised to have them compared with the Bureau standards and Professor Carhart's cells. It will be extremely interesting to see how far these cells agree as to their e.m.f. Let me say in conclusion, that I think it was a very definite advance to make the cells in the form that Professor Carhart has indicated, and if it is proved, as he has shown in the one case, that these cells will remain for a long time without alteration, then the advance is great indeed.

Dr. H. S. Carhart: Of the two methods of making mercurous sulphate employed at the National Physical Laboratory, the one in which fuming sulphuric acid is used to act on mercury appears to me to be the better. In the other one I should think there might be greater danger of hydrolysis. When the mercurous sulphate is dissolved by heat and the solution is poured into distilled water, the danger is that the water will not contain enough acid to prevent hydrolysis.

Doctor Glazebrook: The method that Professor Carhart has referred to is this: the mercurous sulphate is dissolved in strong acid and then poured into a large beaker containing distilled water. In this way the mercurous sulphate is precipitated down to the bottom of the beaker.

Dr. W. D. Bancroft: The behavior of the mercurous sulphate electrode shows that we have here a reversible electrode. The physical chemists make use of the so called calomel electrode and I should like to call attention to the possibility that this is not a strictly reversible electrode, although we always assume that it is. In some experiments tried in my laboratory with mercury as anode in a chloride solution, we did not get mercurous chloride formed. Instead, there is formed a nonconducting film, probably of oxide. In some other experiments we started with mercury and mercurous chloride as anode in the same solution, and found that mercuric chloride was formed. In course of time this reacts with the mercury. Though I should not care to put much stress on these experiments, it seemed to me there was some evidence that the calomel electrode is not, strictly speaking, a reversible electrode. I hope some one will take the matter up.

The other point I wish to make is, that the distribution of potential difference, on which Professor Carhart lays stress, is of course dependent

on the explicit assumption that the calomel electrode has a single potential difference of 0.56 volt. It is believed by Nernst and Billitzer that this is in error by 0.7 volt. While I have not the remotest idea what the true potential difference is, I am perfectly certain that the flowing electrode does not give the true value. If you determine the value of a chloride electrode and of a bromide electrode and combine these two electrodes to a complete cell, you introduce only the potential difference between the two solutions which can be approximated, and yet you find errors under these circumstances running at least 0.07 volt. Consequently, I feel absolutely justified in saying that 0 56 volt is not the true potential difference of the calomel electrode. In fact nobody knows at present what the true potential difference is.

The CHAIRMAN. We are very fortunate, and very much to be congratulated this morning on having with us an eminent authority on electro-metallurgy, Doctor Héroult, of Paris, and I shall call on him next for his paper on "The Electro-Metallurgy of Iron and Steel."

THE ELECTROMETALLURGY OF IRON AND STEEL.

BY P. L. T. HEROULT.

The processes that I am about to discuss form, as a whole, a new metallurgical method for the production of iron and steel based on the employment of electrical energy. They are the result of methodical investigations which I have carried on during a long series of years at the works of the Société Electro-Metallurgique Française de Froges, which company has put at my disposal all the resources of its large establishment.

The "siderurgical method" (Froges-Héroult) is clearly distinguished from all the other processes which have appeared either simultaneously or have been inspired by my disclosures, inasmuch as it completely solves the problem, and is based entirely on experimental data. Among the processes heretofore proposed many are only theoretical conceptions, more or less practicable, such as those of Messrs. Harmet and Gin, which never had an existence except on paper.

In their attempts at a solution, some experimenters meet with insurmountable obstacles, and others have put forth only a partial solution of the problem. We should, however, make special mention of the Gysinge process, which furnishes a practicable and elegant solution of the problem so far as relates to the melting of scrap.

I take the liberty of calling to your attention the fact that if one were to judge by the number and extent of the articles that have been published, he would be apt to obtain a false idea of the relative values of the different processes; it seems that those who have written most extensively on this subject are those who have contributed least to its real advancement. Commercial results furnish the best criterion, and from this point of view the Société Electro-Metallurgique Française de Froges is the only company which has, during the last two years, really manufactured and put on the market a complete series of carbon steels of a quality equal to or better than the best tool steel known.

I shall confine myself, however, to the setting forth of my own investigations, and I shall dwell especially upon the sequence of the conceptions and experiments which have led us to develop a method founded exclusively upon the results of actual experiments, completely solving the problem of making crucible steel commercially, and also of improving the quality of ordinary steel at almost no increase of cost.

In the year 1887 I disclosed an electric furnace designed for the manufacture of aluminum which has been accepted as the first continuous commercial electric furnace. In fact, in consequence of its strong construction, and the method of suspending and regulating the electrode, it is adapted to work continuously for a long period of time; and the addition of a tap hole made it a continuous apparatus. Without any modification it has been successfully applied to many different uses. Willson has applied it to the manufacture of calcium carbide. I have myself used this form of furnace in the manufacture of the first commercial carbide made in France; also to the making of artificial corundum, ferro-chrome, and ferro-silicon, all of which, as electrical products, were first put upon the market by the Société Electro-Metallurgique de Froges.

Ferro-chrome made by this process has the same composition as that made in a cupola, except that it is richer in chromium, the metal carbonizing in contact with the carbon walls of the crucible.

Knowing the great interest that the metallurgist would have in a metal containing a small amount of carbon, I modified my apparatus to obtain this result.

The walls of the crucible were made of ferro-chrome ore, and in a receptacle so formed I placed two electrodes which are in contact only with the surface of the slag, or are even above it; the entrance and exit of the electric current is effected at two arcs in such a manner that the metal never comes into contact with the carbon. The reducing carbon being thus exactly proportioned, it is possible to obtain soft metals, that is to say, metals almost entirely free from carbon. This was the first step in the process of the manufacture of steel by the electric furnace.

So far as regards the use of two electrodes in series. I recognized that this arrangement was not new. Mr. Keller had patented it two months before me, and his own patent was anticipated by the patent of Mr. Bullier, taken out in 1895. Besides the use of two electrodes, certain other conditions are to be met in the manu-

facture of steel, and these essential conditions have not been provided for by any of my predecessors.

Moreover, if the double-electrode furnace is the most practicable, it is not the only one by means of which the production of steel is obtainable. I myself patented on Jan. 29, 1901, a furnace with only one electrode, which accomplishes the same result.

From the time that it became possible to manufacture soft metals, it was obvious that steel could be manufactured by the same method, and it became of great interest to the manufacturer to know that a large electric furnace could be employed for this work, and the inconveniences of blast-furnaces, puddling-furnaces, converting-furnaces, pot-furnaces, etc., could thereby be eliminated. I was attracted at the outset by the idea that I could, in fact, reduce iron ore in my double electrode furnace, the product of the reduction containing only a small percentage of carbon, and then could increase the percentage of carbon to the desired quantity.

It became evident that it was not advantageous to perform all these different operations, namely, the reduction of the ore, the oxidation, recarbonization, etc., in one and the same apparatus. We were, therefore, led to divide it into two parts, and make pig-iron in a special electric crucible. This operation takes place without any special difficulty, providing the indispensable precautions be taken in the arrangement of the charge and in carrying out the operation. In a general way it is not advantageous to transform electrical energy into heat for the reduction of an ore so easily reducible as that of iron. As electric heat is very costly, it must be economized to the fullest extent.

There are two means of economizing this electric heat; one is my patented device called the "Economizer." That device is based upon the principle of combining the total amount of oxygen contained in the ore with carbon to CO. This CO is subsequently burnt by admitting the necessary amount of atmospheric air. The heat generated in this last operation is used to heat the ore previous to its reduction. As a matter of fact the ore falls into the reduction chamber in the molten state. The amount of electrical energy necessary for carrying out the operation is theoretically nil, although in the experiments made in practice it amounted to quite a considerable quantity on account of losses due to radiation. This process did not prove entirely satisfactory owing to the great difficulty of preventing the walls from corroding, and also to the consumption of the reducing carbon, which is large.

The second process, which has always been successful, consists in reducing one-half of the ore in the molten state, while the other half is reduced in the solid state by means of the CO evolved by the first half. If one makes the calculation of the heat units absorbed by the reduction and the heat units evolved by the burning of the carbon in the form of CO^2, he will see that the quantity of electrical energy needed is very small.

I will not discuss further the manufacture of pig-iron, because the electric process, although very interesting, is applicable only under certain conditions and is not likely to supersede the blast-furnace in localities where coal is cheap and is the only source of energy.

I will now proceed to discuss the electrical steel process. This process, which is operated at La Praz in France and at Kortfors in Sweden, produces steel of a quality equal to and superior to the best crucible cast steel. The quality of the raw material from which it is made is a matter of indifference. For instance, steel containing less than .01 sulphur and .01 phosphorus is being made from raw material like scrap, which contains .15 sulphur and .30 phosphorus. The electric furnace has enabled the metallurgist to get rid, once for all, of the necessity of choosing beforehand his raw material and paying a high price for it. The dephosphorising of metals was well understood, although the facilities afforded by the electric furnace are such that it was rendered possible to attain in one operation the results above referred to. The process of desulphurization, which up to the present time has always been considered unsafe and erratic, has been brought to a high degree of perfection. I have discovered the reasons for this erratic behavior involved in the desulphurization of steel, and by means of the electric furnace we have the entire operation under perfect control. We can regulate the temperature as we choose and carry out the work without any oxidation by the air.

I make the claim that at a cost not exceeding half a dollar a ton, I can make out of any steel delivered in the molten state, that is, as tapped out of a Siemens furnace, or from the Bessemer converter, a metal of any desired composition containing less that .01 sulphur and .01 phosphorus. It is evident that the electric process must not be considered as a steel-making process, but as an adjunct to existing plants and apparatus. By means of this electrical adjunct, the commercial value of the product has been greatly increased. It is obvious that there is a great advantage in using a metal free from

impurities, such as sulphur and phosphorous, and the day will come when the requirements of the public and the specifications of government contracts, railroads, etc., will be such that the iron-masters will have to furnish material thus purified and answering these conditions. They will have no excuse for not doing so, because there is now put at their disposal a cheap method of accomplishing the desired result. I am far from predicting that the electrical furnace process will supersede the older metallurgical one, but it will and must cause a revolution so far as the quality of the metal used in the industry is concerned.

Discussion.

Prof. J. W. Richards: I have listened with great interest to Doctor Héroult's paper, because I know he is in the forefront of those who are beginning this method of manufacture of steel. The manufacture of the higher grades of steel has been the only available point of attack, because of the present cost of electric manufacture, but the manufacture of these high grades is now a commercial success. The advantages of electric manufacture are so great, especially in view of the inevitable advances which are going to take place in the development of electric furnaces in the next five or six years, that I have no doubt that the larger part of the fine steel consumed is going to be made in this way. When we consider that the finer grades of steel, such as armor plate and steel for guns, is sold at several hundred dollars a ton, the increased cost of the electric manufacture of the raw material—provided it gives a material lower in sulphur and phosphorus and free from nitrogen—is negligible. The greatest development of this manufacture in the near future will be in the commercial grades of steel, such as soft steel. I do not think it impossible that within a few years there will be a large steel industry in Canada, where pig iron is cheap and where there are all inducements for setting up an electrical industry. A few years more, and I think it will find a place in the United States, where it will probably be used as an adjunct to the open-hearth furnace. For temperatures up to the melting point of pig iron, it is probable that the use of producer gas and the ordinary furnace will always be most economical; but for the additional 500 degrees necessary to reach to the melting point of steel, the electric furnace is, I believe, even under present conditions, the more economical of the two apparatus, and the combination of the gas furnace with the electric furnace will, I believe, be the next subject of development in the electro-manufacture of steel. I think we are in a period of transition, and that this is the beginning of a great commercial revolution in the manufacture of this most important product.

Mr. E. H. Whitlock: From the manufacturer's side of the question I would like to ask what current-density is used in the electrodes, and whether it is desirable for this to remain about what it is at present? I had the privilege of visiting a plant in West Virginia some time ago,

and at that point they required something like 125 amperes per square inch, which seemed to be rather excessive.

Mr. W. McA. JOHNSON: I have listened to the paper of Doctor Héroult with great interest. Any one connected with the operation of large metallurgical works is forced to the conclusion that there is a vast difference between the writing of a paper on the probable success of a process and the actual working of that process on a large scale. A point which I shall try to bring out in my paper tomorrow is this, that the best criterion of a new process is the actual production of the finished material. Right here is where Doctor Héroult's work is to be admired.

The second point which this paper of Doctor Héroult has elucidated and which is one of a few general principles to be given in my paper, is the principle that the electric current can be best used by the metallurgist for the finishing of metallurgical work. This principle was first called to my attention by Col. Robert M. Thompson, formerly president of the Orford Copper Company, and Mr. Victor Hybinette, superintendent of the same company, when I was in its employ. The principle is a very general one. Tomorrow I will try to give a few of its applications to the metallurgy of this country, as far as I have seen it. But both of these ideas are better illustrated by this paper than I can hope to do.

The following paper was then read by Mr. S. E. Whiting:

THE PRESENT STATUS OF THE EDISON STORAGE BATTERY.

BY DR. A. E. KENNELLY AND MR. S. E. WHITING, *Harvard University.*

The following paper is presented on behalf of Mr. Thos. A. Edison, as a brief synopsis of the results obtained with his storage battery up to the present date.

HISTORY.

About 1898, Mr. Edison began seriously to investigate alkaline storage cells. After trying a very great number of combinations, the nickel-iron couple became fairly well developed in 1900.

The first type of cell put into service in vehicles was named Type C. This was an 18-plate cell (9 of iron and 9 of nickel), weighing complete 17 1/2 lbs. (7.95 kilos). At 20 amperes discharge (9.5 hours) to 0.75 volt the average potential difference was 1.23 volts and the quantity 191 amp-hours representing 234.9 watt-hours or 13.4 watt-hours per lb. (29.6 watt-hours per kilo). At 120 amperes discharge (1.4 hours) to 0.75 volt, the average potential difference was 1.03 volts and the quantity 171 amp-hours, representing 176 watt-hours or 10.06 watt-hours per lb. Several hundred of these cells were made up and are still in use in vehicles at the factory.

This Type C cell was not regarded as entirely satisfactory because it did not promptly recover its full normal voltage after heavy rates of temporary discharge. This seemed to indicate an inadequate circulation of electrolyte in the cell and pointed to a reduced current density; i. e., to a larger plate-surface for the same mass and volume of active material. The improvement required new tools and months of delay, but was nevertheless undertaken, and the new cell developed was named Type D.

The type of D cell was first completed in May, 1903. It was a 28-plate cell (14+ and 14—) weighing 17.8 lbs. (8.05 kilos) and occupying the same space as the 18 plates of Type C, thus providing

an increase of about 50 per cent in active surface with a corresponding reduction in briquette thickness, to the improvement of circulation.

Tests of the Type D cell were made not only at the Edison laboratory but also by several independent experimenters both in this country and in Europe. These tests will be referred to later. The factory tests of Type D showed at 20 amperes discharge (8.45 hours) to 0.75 volt, the average potential difference of 1.28 volts and the quantity 169 amp-hours, representing 216.5 watt-hours or 12.18 watt-hours per lb. (26.9 watt-hours per kilo). At 120 amperes (1.38 hours), to 0.75 volt, the average potential difference was 1.17 volts and the quantity 165 amp-hours, representing 193 watt-hours or 10.85 watt-hours per lb. (24 watt-hours per kilo). The corresponding internal resistance is 0.0013 ohm.

The change from Type C to Type D had succeeded in enabling the cell promptly to return to its normal e.m.f. after temporary heavy discharges, and improved the output under heavy discharge from 10.06 to 10.85 watt-hours per lb. (22.2 to 24 watt-hours per kilo). On the other hand, the output at low rates of discharge had somewhat suffered by the change, and the new cell was also found to be somewhat unbalanced in the individual capacities of the + and — plates, there being an excessive capacity in the iron plates.

A further modification was, therefore, made in the cell, resulting in the production of Type E, the latest type.

Types C, D and E have the same height, length and general external appearance and differ externally only in their breadth. Type E is the cell now manufactured and placed on the market in three sizes, which differ only in the number of assembled plates. The cell of Type E tested by the author's and here considered is E-18, having 12 nickel plates and 6 iron plates. The weight of the E-18 cell complete is 12.66 lbs. (5.75 kilos). The normal rated delivery of these cells is 114 amp-hours, which is practically the same at either the 30-ampere or 120-ampere discharge rate. At the 30-ampere rate (3.8 house), the mean potential difference to 0.75 volt is 1.234 volts, representing an output of 141 watt-hours or 11.1 watt-hours per lb. (24.6 watt-hours per kilo). At the 120-ampere rate (0.95 hour), the mean potential difference to 0.75 volt is 1.04 volts, representing an output of 118.5 watt-hours or 9.38 watt-hours per lb. (20.7 watt-hours per

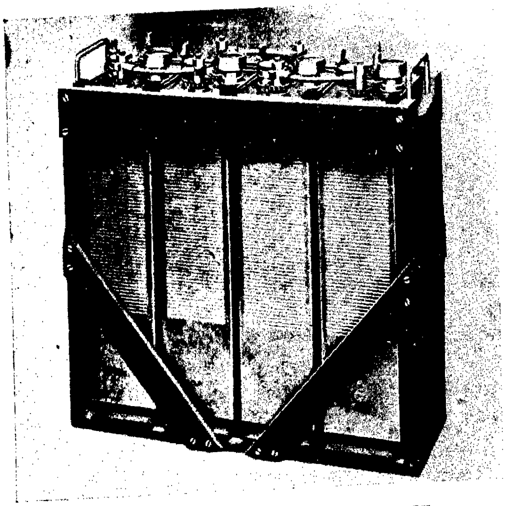

Fig. 1.— Parts of Edison storage battery.

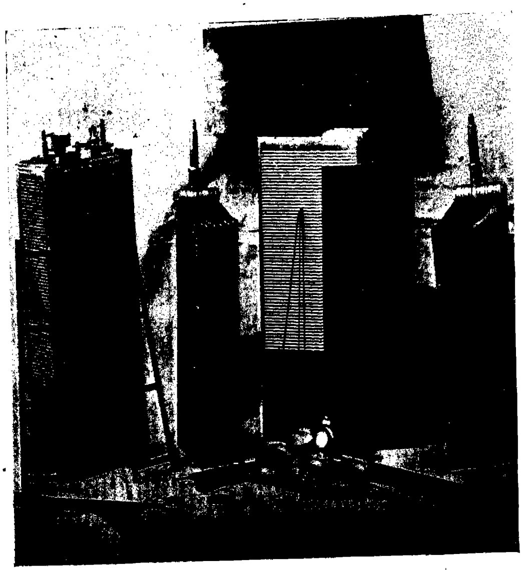

Fig. 2.— Edison storage battery.

kilo). Although the above are the normal rated capacities, the full capacity of the cell is found to be about 140 amp-hours, which makes the total output at 30 amperes, 173 watt-hours and at 120 amperes 145 watt-hours; or the specific output 13.7 watt-hours per lb. (30.2 watt-hours per kilo) and 11.5 watt-hours per lb. (25.4 watt-hours per kilo) at the two rates respectively.

Construction of Type E.

The construction of the cell is shown in Fig. 1 which exhibits the various parts both separate and assembled. The containing cell, as also the grids and pockets, are made of thin sheet-steel plated by a special process. The jar completely encloses the element and the lid is soldered permanently in place. There are four openings in the steel top. Two of these are insulated by rubber bushings through which the terminal posts project. The third opening is a filler-hole with gas-tight hinge-stopper. The fourth opening is a gas-vent provided with a valve and gauze screen to prevent escape of entrained liquid.

The insulation between the walls of the can and the enclosed element is all of hard rubber. On the bottom is the four-barred grating, seen on the right-hand side of the figure, and 0.4 in. (10.2 mm) deep. On the ends are ladder-like frames giving about 0.11 in. (2.8 mm) clearance and grooved to hold the edges of the plates. On the sides are solid sheets 0.014 in. (0.56 mm) thick. It has been found necessary to subject all the rubber insulation to a special chemical treatment to prevent a foaming action on the alkaline electrolyte.

Between the plates are threaded four-cornered rods of rubber about 0.1 in. (2.5 mm) thick and spaced 0.57 in. (14.5 mm) apart. The distance between opposed plate surfaces is about 0.04 in. (1 mm).

Plates of like polarity are bolted to a horizontal-bar at the top provided with spacing washers and joined to the vertical terminal post.

For use in vehicles the cells are grouped in wooden trays (Fig. 2) containing 3, 4 or 6 cells each. Connections between cells are ingeniously made by taper lugs and each jar is insulated from its neighbors and from the base by spacing blocks and a rubber pad, respectively.

The grid itself, Fig. 3, and the pockets containing the active materials are identical for both positive and negative electrodes. The grid is 9.25 in. high (235 mm)— excluding the lug — 4.75 in. (121 mm) wide and 0.015 in. (0.38 mm) thick. It contains 24 rectangular holes, each 2.95 in. (.75 mm) high and 0.5 in. (12.7 mm) wide. Into these holes are fitted the pockets illustrated in Fig. 4. These are made up of strips of 0.003 in. (0.076 mm) steel, having flanged edges that telescope together to form the pocket or container of the active material. These pockets have each about 5000 perforations.

The active material of the positive plate is an oxide of nickel in finely-divided form commingled with a conducting substance such as flake graphite, in order to improve the conductivity of the mass. The active material of the negative plate is finely divided iron similarly commingled with a conducting substance. The electrolyte is a 20 per cent aqueous solution of potassium hydrate.

In assembling, the pockets are filled with active material, closed and inserted in the holes of the grid. The plate is then subjected to a pressure of 150 tons for the purpose,— first, of flanging the pockets over the holes in the grid, in order to lock them firmly in position; and second, of corrugating the surface of the pocket, in such a manner as to provide adequate elastic movement of the envelope in view of the contraction and expansion of the contents.

The weight of the active material in its initial condition and including the conducting material is about 3.2 grammes per pocket for the nickel and 4.6 grammes for the iron plate. This represents a total quantity of 922 grammes positive active material, and 662 grammes of negative active material in an E-18 cell. The weight of electrolyte per cell is 3.1 lbs. (1.40 kilos) at a normal density of 1.190, which represents about 25 per cent of the total weight of the cell.

The cell is at present manufactured in three sizes stated in the following Table:

FIGS. 3 AND 4 — DETAILS OF EDISON STORAGE BATTERY.

Type.	Positive plates.	Negative plates.	Capacity in ampere-hours.		Normal charging current.	Normal charging time.	Weight complete		Dimensions over all (excluding trays).							
									Length.		Breadth.		Height.		Volume	
			Normal.	Maximum	Amp	Hours	Lbs.	Kilos	Ins	Cms.	Ins	Cms.	Ins	Cms.	Cu ins	Cu cm
E-18.....	12	6	110	140	40	3.75+	12 5	5.66	5.	13.0	2 6	6.6	13 2	33.5	175	2,874
E-27.....	18	9	165	210	60	3 75+	17 5	7.95	5 1	13 0	......	.. ...	13 2	33 5	......	...
E-45.....	30	15	275	350	100	3.75+	30.0	13.6	5.1	13.0	......	......	13 2	33 5	. ....	.....

Chemical Theory.

The Edison cell is of the oxygen-lift type. That is to say, the process of charging consists in driving oxygen electrolytically from the negative to the positive plate. During discharge the oxygen leaves the positive plate and enters the negative plate. The chemical actions in the cell have not, as yet, been completely investigated.* The following conditions may, however, be accepted provisionally as forming a working theory:

Condition.	Positive plate	Electrolyte	Negative plate.
Charged	NiO_2 NiO_2	KOH H_2O KOH	Fe
Discharging ..	$NiO_2\overset{+}{K}$ $NiO_2\overset{+}{K}$ H_2O	$\overset{-}{HO}$ $\overset{-}{HO}$	Fe
" . .	$+Ni_2O_3$ KOH KOH	H_2O	FeO—
Discharged ..	Ni_2O_3	KOH H_2O KOH	FeO

The cycle represented in the above table shows that during discharge the electrolyte divides into potassium cations and hydroxyl anions, the former being directed toward the positive plate and the latter toward the negative plate. On arriving at these plates the ions give up their respective charges. At the positive plate, the potassium robs the nickel oxide of a portion of its oxygen and, in combination with the water present, forms new molecules of potassium hydrate, the original electrolyte. At the negative plate the hydroxyl ions deliver oxygen to the ion and form water. Thus the electrolyte tends to become concentrated in the pores of the positive plate, and attenuated in the pores of the negative plate. Diffusion ultimately destroys this difference of concentration and leaves the electrolyte in its original condition, since at any instant the total quantity of water and of potassium hydroxide (including the pores of both plates), remains the same.

* E. F. Roeber. *Transactions* A. E. S. Vol. 1, 1902. M. V. Schoop, *Electrochemical Industry*, July and August, 1904.

It would appear from the form of e.m.f. curve during complete discharge, as shown in Fig. 5, that after the cell has become almost entirely discharged other stages of oxidization develop, and further investigation may show that the outline of the chemical cycle above presented is very incomplete. Whatever the complete cycle may be, it is, in all probability, however, of the type indicated.

It would seem that neither the plates of nickeled steel nor the active materials within them are subject to local or chemical corrosion, or solution, in the electrolyte of potassium hydroxide. For this reason the cell is chemically stable either in the charged discharged or any intermediate condition.

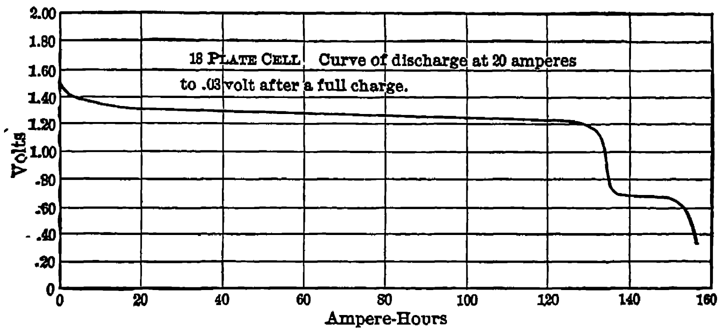

FIG. 5.—P. D. CURVE FOR E. 18 CELL.

ELECTRICAL THEORY.

Electromotive Force.

Various observations both of the authors and other observers show that the discharge curve of e.m.f. of the Type E cell possesses the following peculiarities:

(1) An initial period of rapid descent occupying about 10 per cent of the delivery period.

(2) A nearly steady gradient of gradual descent continuing until within about 10 per cent of the end of the whole delivery period.

(3) A final period of rapid descent occupying the last 10 per cent of the delivery period (assumed as stopping at a potential difference of 0.75 volt).

A fair sample of this curve is represented by the heavy line *a b c d* in Fig. 6, where *ab* is the initial descent, *bc* the nearly uniform descent, and *cd* the final rapid descent. The initial

e.m.f. at a is influenced by the previous history of the cell, more particularly by the time which has elapsed since the close of the preceding charge. The range of initial e.m.f. is between 1.35 and 1.65 volts. It would seem that this e.m.f. depends upon the amount of gases remaining after the charge, occluded in the pores of the cell.

The e.m.f. at and near the end of the discharge is also somewhat variable, depending in some measure upon the rate and nature of the discharge. It clearly accompanies the exhaustion of the active materials.

Between the points b and c, the gradient of descent is substantially uniform and approximately independent of the discharge rate within the usual working limits. This diminution of e.m.f. may possibly be due to the increasing thickness of the layer of effete material formed by the progressive exhaustion of the active material.

If the curve $a\ b\ c\ d$ be integrated, the mean ordinate is found closely to approach the actual ordinate at C or the point of half delivery. This means that a straight line $A\ C\ D$ may be chosen nearly coinciding with the steady gradient of the actual curve bc. This is shown in a dotted line $A\ C\ D$ in the figure. The area above this line $A\ a\ b$ at the beginning is approximately equal to the area below the line $c\ D\ d$ at the end. These areas represent, therefore, sensibly equal and opposite quantities of electrical energy, with respect to the curve $a\ b\ c\ d$. Consequently, we may for practical purposes replace the actual curve $a\ b\ c\ d$ by the equivalent straight line $A\ C\ D$, which is represented by the formula

$$e = 1.37 - \frac{x \times 0.14}{100} \text{ volts}$$

where x is the percentage already yielded, of the full delivery. The mean discharge e.m.f. is, therefore, 1.30 volts. This approximation greatly simplifies practical computation with the Edison battery.

Internal Resistance.

It has been observed both by the authors and by other experimenters that the internal resistance of an Edison Type E cell is substantially constant during the main working portion of the discharge corresponding to bc in Fig. 6. Thus in the E-18 cell, the internal resistance at ordinary temperatures is about 0.0022 ohm. This would correspond to 0.0278 ohm in a Type E similar cell

weighing 1 lb.; or to 0.0126 ohm in a cell weighing 1 kilo. The internal resistance is slightly less at the beginning of the discharge, but becomes considerably greater near the end of the discharge. Since, however, this rise in resistance occurs only during a small portion near the end of the delivery, its effect in the total discharge may be neglected for most practical purposes.

The internal resistance does not vary greatly with the discharge rate within the usual working limits of 0 — 150 amperes. In other words, the drop of pressure in the cell is approximately proportional to the discharging current strength.

Power.

The maximum amount of power obtainable in the external circuit of any cell is $\frac{e^2}{4\,r}$ watts; where e is the actual e.m.f. and r the actual internal resistance of the cell. Under these conditions the cell will work at 50 per cent efficiency, with equal internal and external resistance. In other words, it is impossible to obtain from any cell a greater amount of external power than corresponds to the above expression, which represents the maximum power of the cell. Taking the mean e.m.f. of the Edison Type E-18 cell as 1.3 volts and the internal resistance as 0.0022 ohm, the maximum power is 192 watts or about 1/4 horse-power or 15.15 watts per lb. (33.4 watts per kilo) at a current strength of 296 amperes, corresponding to a discharge time of less than one-half hour. We have taken a current averaging 250 amperes from such a cell on approximate short-circuit (through heavy leads and an ammeter) for a period of 30 minutes.

The practical rate of power delivery at 150 amperes is $\{1.3 - (150 \times 0.0022)\}\ 150 = 145.5$ watts, or 11.5 watts per lb. (25.4 watts per kilo). This is on a par with the full-load output of good dynamo machines.

Energy.

The energy liberated in an Edison E-18 cell is 1.3 volts $\times$ 141 amp-hours = 183.3 watt-hours = 14.48 watt-hours per lb. (31.9 watt-hours per kilo) and this liberation of energy is constant to a first approximation for all rates of discharge within the working limits. The amount of this liberated energy which is delivered in the external circuit depends only on the electrical efficiency of

the circuit, or on the drop of pressure in the cell. Thus, at 90 per cent electrical efficiency, or 10 per cent internal drop (corresponding to about 60 amperes in the E-18 cell), the externally delivered energy would be $183.3 \times 0.9 = 165$ watt-hours.

It can be shown that if any Edison Type E battery, in any grouping of cells, be discharged at the rate of p watts per unit mass, reckoned at the mean voltage of discharge, the electrical efficiency, η, of the battery circuit will be $\eta = \frac{1 + \sqrt{1 - n}}{2}$, where $n = \frac{p}{P}$ and P is the maximum power per unit mass or $\frac{e^2}{4mr}$, where m is the mass of a cell.

Thus if a battery of 68 Edison Type E-18 cells be discharged at 120 amperes or 124.3 average external watts, the total external power will be $68 \times 124.3 = 8454$ watts, and the total weight being 861 lbs., the power rate per lb. taken from the battery is 9.83 watts. The maximum power rate is, however, 15.15 watts per lb. as above; so that the ratio $n = \frac{9.85}{15.15} = 0.65$. The electrical efficiency of the battery circuit is, therefore,

$$\eta = \frac{1 + \sqrt{1 - 0.65}}{2} = 0.796$$

or 79.6 per cent. The delivery per lb. of battery will, therefore, be $14.5 \times 0.796 = 11.5$ watt-hours per lb., and the entire battery will deliver 9900 watt-hours to the external circuit, when discharged to 0.75 volt P. D. per cell. The same formula applies to *all* batteries capable of maintaining definite values of e and r under load.

Charging Conditions.

Electromotive Force.

The charging e.m.f. of an Edison cell is approximately 1.6 volts (somewhat greater at the outset) until about 60 per cent of the charge has been stored, when it rises to about 1.75 volts, simultaneously with increased evolution of gases. This rise is, therefore, apparently connected with gaseous polarization. To the e.m.f. of the cell must be added the drop in internal resistance, in order to find the potential difference at charging terminals. The mean e.m.f. of the cell during charge may, therefore, be taken as roughly 1 2/3 volts. The resistance of the cell during charge is approximately the same as during discharge, being greater at the outset

of the charge, corresponding to the condition of resistance at the end of the discharge.

Gassing.

During the charge of Edison cells, bubbles of gas are liberated at both plates, oxygen at the anode or positive plate, and hydrogen at the cathode or negative plate. The collected gases form an explosive mixture. In the ordinary charging process there is a distinct evolution of gas at the outset which reaches its maximum in about a quarter of an hour. The gassing then decreases to a lower steady value which continues until about 60 per cent of the charge, after which it rapidly rises to a steady much higher value than at first. The electrical energy expended in the liberation of these gases is practically all lost.

To replace the water thus lost by decomposition during charging, a small quantity of distilled water has occasionally to be added to the cells through a filler conveniently adapted to this purpose.

Efficiency.

Since the mean e.m.f. of discharge is approximately 1.3 volts, and the mean e.m.f. of charge approximately 1.67 volts, it follows that the superior limit of watt-hour efficiency in an Edison cell is $\frac{1.3}{1.67}$ or 78 per cent. In practice it is always less than this, due to internal drop.

The efficiency may best be examined first in relation to the voltage of charge and discharge, and second, in relation to the electric quantity charged and discharged.

1. If there were no drop of pressure due to internal resistance, either in charging or in discharging, and all the electricity charged in the cell (as expressed in coulombs or amp-hours) were discharged, the amp-hour efficiency of the cell being thus 100 per cent, the watt-hour efficiency would be 78 per cent or thereabouts. This figure can, in fact, be approached by employing very low rates of charging and discharging; i. e., by taking many hours to each process. On the other hand, the more rapid the charge and discharge, the greater the *IR* drop in the cell, and the less the efficiency, even on the assumption of 100 per cent amp-hour efficiency. Thus at 60-amperes charging and discharging rates, the potential difference in charge would average about 1.8 volts in the E-18 cell and the potential difference in discharge would average about 1.17

volts to the 0.75 volt limit, representing a watt-hour efficiency of 65 per cent, with 100 per cent amp-hour efficiency.

2. The Edison cell would manifestly possess an amp-hour efficiency of 100 per cent if no gases or irreversible substances were generated in its cycle of chemical action. Thus if a certain number of grammes of iron were reduced and a certain number of grammes of nickel were oxydized by one ampere-hour of charging current, and no other action took place, then on discharge the reconversion of these masses of active material would develop the complete ampere-hour of electricity. On the other hand, every gramme of hydrogen (or the equivalent mass of oxygen) liberated and discharged from the negative plate during charge absorbs 26.8 amp-hours of electricity, which is not returned to the circuit during discharge. The amp-hour efficiency of the Edison cell is, therefore, determined by the amount of gas escaping during the charge. This in turn depends upon the rate of charge, or charging-current strength, since the greater this strength the greater the drop in internal resistance, and the sooner the plates are brought to that difference of potential at which the water is rapidly decomposed.

At high rates of charge, then, the watt-hour efficiency of the cell must fall off, not only because of the voltgage drop, but also on account of the reduction of amp-hour efficiency in gasification.

Nevertheless, in many cases, and particularly in automobile work, this sacrifice of energy is amply warranted by the convenience and saving of time effected by rapid charge. The normal charging time of Edison E cells is about four hours. In cyclical charges and discharges of four hours each, the amp-hour efficiency is about 75 per cent and the voltage ratio 70 per cent, so that the watt-hour efficiency may be taken in round numbers as 50 per cent ($0.75 \times 0.7 = 0.525$). It is possible, at a still greater sacrifice of efficiency, to charge the cell at fully double the above normal rate.

Tests.

Laboratory Tests.

Tests of the various types of Edison cell have been made in great numbers and in great variety at the Edison laboratories. Tests have also been made in Europe on Type D cells and published near the end of the year 1903 by Finzi and Soldati at Milan (Associazione Elettrotecnica Italiana, 12th October, 1903), by M. E. Hospitalier at the Central Laboratory of Electricity in Paris (*L'Industrie Elec-*

trique, pp. 493–497, November, 1903), and by Mr. W. Hibbert and Dr. J. A. Fleming, in London (*Journal* of the Institution of Electrical Engineers, Vol. 33, No. 165, April, 1904, pp. 203–238). The authors also have conducted at Harvard University a number of tests on cells of Types D. and E. All of these tests are fairly concordant and in conformity with the data given in this paper.

The essential results of these various tests are represented in the accompanying chart, Fig. 7. This chart gives the output of the Edison cell (per unit mass) at varying power rates of discharge. Curves I, II and III represent the laboratory tests obtained for Type D by the Laboratoire Central d'Electricité, Mr. Hibbert and M. Hospitalier, respectively. Curve V represents the corresponding values for the E-18 cell on normal-rated capacity and delivery. Curve IV represents, on the other hand, the corresponding values

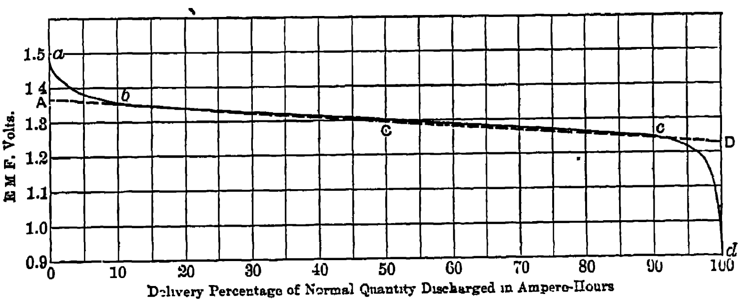

FIG. 6.—ACTUAL AND EQUIVALENT E M.F. CURVES DURING DELIVERY.

for the E-18 cell, when operated under laboratory conditions of maximum capacity and delivery. In practice, the output may be expected to fall between these two curves, IV and V.

Although the authors' tests of the Type E cell have been confined to the E-18 12 1/2 lb. cell, factory tests of the larger sizes of this latest show about 12 per cent greater maximum output per unit mass than corresponds to Curve V. This may be accounted for by the lesser proportion of dead weight (solution, jar and connections) than is presented in the E-18 cell.

Automobile Tests.

Much experience has been attained in actual service from the Edison battery on automobiles. This experience has led to the elimination of some of the minor practical difficulties that any new battery always encounters. The successive improvements in the

battery have, in fact, been due to the perception of defects discovered in actual vehicle practice.

Mr. H. M. Wilson of the Boston Edison Illuminating Company reported some observations on an Edison automobile battery of 68 D-28 cells regularly employed in a single-seat service wagon of the Boston company carrying two persons. The weight of the battery was 1260 lbs. (570 kgs). In four rows of 17 cells each, it occupied a space (including trays and lugs) of about 6 ft. x 2 ft., and was about 1 1/3 ft. high, thus having an over-all volume of 16 cu. ft. (0.45 cu. meter). The weight of the vehicle complete was about 3150 lbs. (1425 kgs). During 22 working days of regular urban service in October and November, 1903, the battery received 1380 amp-hours at 110 volts, or 151.4 kw-hours; and delivered at terminals 68.85 kw-hours at an average potential difference of 85 volts. The amp-hour efficiency was 58 per cent, the volt efficiency, 77 per cent, and the watt-hour efficiency, 45 per cent. The distance run was 324 miles, or 14.7 miles daily, and the energy consumed per mile was 0.47 kw-hour. These results are not only much surpassed by similar batteries of type E, but they are also stated to be exceeded by later batteries of the type D here referred to. Consequently, these results may be regarded as conservative.

Durability and Depreciation.

It would seem that the Edison cell is so durable that no electrical depreciation is discernible in the cells during the three years' total experience of the practical construction of the battery. No mechanical corrosion of the plates or pockets has been discernible during that time and no depreciation seems to have yet occurred in the active material, judging from the capacity tests of cells which are stated to be as great at the present time as they were when the cells were first constructed. The authors have recently confirmed this observation in the case of Type D cells that have run nearly 3000 miles in an automobile of the Edison Company in Boston. The capacity of these cells was found to be equal to that of new cells of the same type. Two of these cells were opened for examination and the sediment in them collected and dried. The dry sediment weighed 3.9 and 7.1 grammes respectively, probably less than one-third of 1 per cent of the active material in the grids. In fact, a new cell freshly set up will show about this quantity of material washed by the solution from the external surface of the plates. No

signs of depreciation or corrosion appeared on any of the plates or connections.

Effect of Rest.

According to observations at the factory, Edison cells lose 15 per cent of their amp-hour charge in eight weeks of idleness. Another test showed 11 per cent of loss by standing one week. Hibbert's tests on Type D showed 9 per cent loss in 48 hours and 27 per cent in 26 days. Hospitalier's tests on Type D showed less than 10 per cent loss after 24 days. A test of the authors on four Type E-18 cells gave, after 26 days' idleness, 100 amp-hours per cell. This represents a loss of 9 per cent of the normal-rated capacity of the cells or 28.6 per cent of the maximum-rated capacity. At a corresponding charge the delivery within 24 hours would have been about 140 amp-hours.

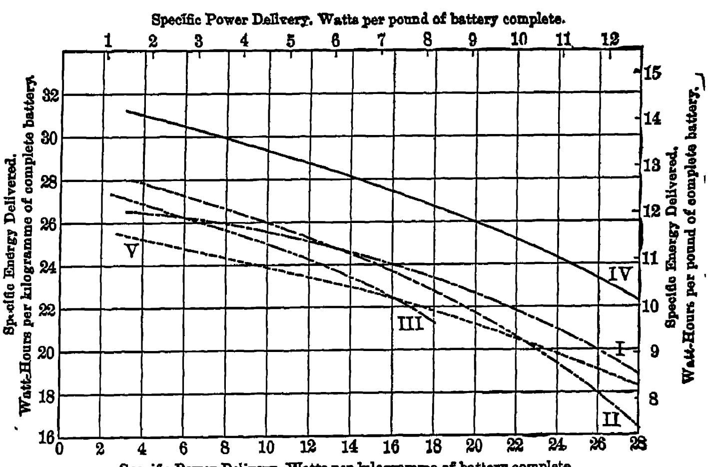

FIG. 7.—CURVES SHOWING USEFUL ENERGY DELIVERED IN DISCHARGING TO A P.D. OF 0.75 VOLT AT VARYING POWER-RATES OF DELIVERY.

All of the tests show that the cells are remarkably immune from deleterious effects due to careless treatment. Cells have been allowed to dry out, have been permanently short-circuited or even charged in the wrong direction. These cells have shown a full restoration of their capacity after a prolonged restoring normal charge.

Conclusions.

The Edison nickel-steel alkaline storage cell, in its large output at heavy discharge rates, its low depreciation in capacity and its durability under severe and adverse treatment, approaches the capabilities of a piece of mechanical apparatus more nearly than is ordinarily credited to electrolytic structures. For this reason it is specially adapted to automobile service, where the treatment is abnormally arduous and severe.

The authors desire to express their indebtedness to Mr. Edison for the cells which he placed at their disposal for test as well as facilities for becoming acquainted with the facts concerning their manufacture. Also to his assistant, Mr. R. A. Fliess, of the Edison Storage Battery Company, who very kindly placed an invaluable collection of experimental data at our disposition. We are also indebted to Mr. C. L. Edgar, president of the Boston Edison Illuminating Company, for the use of his battery in tests and information concerning the same from his assistants.

Discussion.

Prof. C. F. Burgess: I should like to refer to some of the tests which Messrs. Almond and Davidson, in the department of applied electrochemistry of the University of Wisconsin, have carried out on the Edison cell during the past year. Their results corroborate, to a considerable extent, the figures given in the paper just presented. The tests were made on two type "E-27" cells taken from an automobile in service in Madison, and submitted to 20 charges and discharges. The charging rate was 6 hours, and the rate of discharge varied in different runs from 1 to 6 hours. In no case was a watt-hour efficiency obtained which materially exceeded 50 per cent, even on the lower rates of charge and discharge. It seems possible, however, to obtain a slightly higher efficiency, by decreasing the amount of charge given to the battery.

Tests were made on the loss of charge while standing on open circuit, and it was found that standing fully charged during 30 days and then discharged at a five-hour rate, the loss of ampere-hours was 25, or 19.5 per cent. In regard to gas evolution, some interesting observations were made. The total volume of gas on the charge and discharge was measured on several runs. It was found that with a 22-ampere charging rate there was .59 of a cubic foot of gas liberated during the charge, as measured by an ordinary gas meter. At a 35-ampere charging rate the amount of gas liberated was .63 of a cubic foot, while at the rate of 175 armatures—a very high rate—the total amount of gas liberated was 1.59 cubic feet, thus showing where a good deal of the energy goes. It was found that during discharge at a low rate there was about 01 of a foot of gas liberated, and at the highest rates of discharge gas was not liber-

ated in sufficient quantities to be measured. I would like to ask the authors of the paper if they made any observations upon the amount of gas liberated during the charge or discharge of the cell as confirming the above mentioned measurements?

Dr. A. E. KENNELLY: We made no measurements of the amount of gas liberated in the cells.

The gist of our paper is that the Edison cell appears to possess a definite energy-storage capacity per unit weight (in the measurements detailed in our paper about 32 watt-hours per kilo), of which any desired portion may be delivered to the external circuit by suitably proportioning the external resistance, or, in other words, by assigning the electrical efficiency of discharge. Expressing the same result in another way, the energy delivered to the entire discharging circuit (both internal and external) seems to be practically the same within all working ranges, and the externally delivered energy only varies as the external resistance forms a larger or smaller portion of the total resistance in the circuit. The externally delivered energy will be 60, 75, or 90 per cent of the total charge according as the external resistance is 60, 75, or 90 per cent of the total resistance in the discharging circuit, at least to a first approximation sufficient for most practical purposes.

This nearly constant release of energy into the discharging circuit and the hardihood of the cell under severe usage are, perhaps, the most salient points in the cell's behavior.

Mr. S. S. SADTLER: I would like to ask Messrs. Kennelly and Whiting whether they noticed any trouble due to the alkaline solution taking up the carbonic acid from the air. I should think there would be a loss of efficiency in that way.

Mr. S. E. WHITING: Owing to the construction of the cell, which is virtually sealed hermetically, the carbonic acid of the air has very little opportunity to enter the cell.

The Chairman then invited Dr. J. W. Richards to read his paper.

ELECTROLYTIC CONDUCTION.

BY PROF. JOSEPH W. RICHARDS, *Lehigh University.*

Faraday divided conductors into two classes, calling them conductors of the first and of the second classes. The first class conducted the electric current without chemical decomposition, their conductibility decreased with increasing temperature and *vice versa;* they showed no back e.m.f. when the current was stopped. The second class were decomposed when the current passed, that is, the products of their decomposition appeared at the terminals, on passing the current, their conductibility increased with increasing temperature and *vice versa,* and they showed a back e.m.f. when the current was stopped.

Later, Ohm showed that for conductors of Faraday's first class $R = \frac{E}{I}$ and that R is a function of the length and cross-section of the conductor. The specific resistance, i. e., the resistance in ohms of a centimeter cube, is a natural property of the conductor, comparable with its specific gravity or any other physical property. These principles discovered by Ohm are so firmly fixed with regard to conductors of the first class that we will assume their truth in our further discussion.

Later it was shown by Thomson that Ohm's law also applies to conductors of Faraday's second class, if from the applied e.m.f. there be first substracted the e.m.f. corresponding to the work of chemical decomposition which was being accomplished by the current. If E be the total applied e.m.f. and E^1 be the e.m.f. corresponding to the work of chemical decomposition, then $R = \frac{E-E^1}{I^1}$ and R is also here found to be, in this way, a function of the length and cross-section of the conductor. If the terminals be so chosen that the electrolyte is exactly reconstituted by the use of a soluble anode of the same nature as the cathion which is being deposited, then the algebraic sum of the chemical work being performed is zero, and, E^1 being zero, $R = \frac{E}{I}$ which permits of a

very simple and accurate verification of Ohm's law for this class of conductors.

It is admitted then that conductors of Faraday's second class, viz., electrolytic conductors, possess specific conductivity and interpose specific resistance to the passage of the current which is in all respects similar to conductors of the first class. The only difference is that conductors of the second class are decomposed by the current passing through them, and, therefore, absorb an additional e.m.f. corresponding to the chemical potential of the chemical decomposition performed.

Much discussion has been raised regarding the mechanism of the conduction of electricity through these two kinds of conductors. Since no one knows how electricity is conducted through metals, or conductors of the first class, the discussion has been very one-sided, being principally confined to the elaboration of a theory of electrolysis applicable only to conductors of the second class; a theory which links together as one phenomenon the conduction of electricity through the body of an electrolyte and the resulting decomposition produced at the electrodes. According to this theory, the electrolyte is divided throughout as soon as it begins to transmit current into two oppositely charged constituents which take up their march toward the opposite electrodes. Modern electro-chemistry has determined with great industriousness what these charged ions are in a great many electrolytes, what their relative and even their actual velocities are through the electrolyte at different temperatures, and explains the appearance of products of decomposition at the electrodes by postulating the discharge of these charged ions as soon as their migration brings them into actual contact with the electrodes.

If this view is correct, then electrolytic conduction is *per se,* in the body of the electrolyte, different in nature or kind from metallic conduction, in which we know that there is no migration of ions or carrying of the current by the convective action of charged ions.

The object of this paper is to present the thesis that, as far as the conduction of electricity through the body of the conductor is concerned, there is, as far as we can determine, complete identity between metallic conductors and so-called electrolytic conductors.

Marvin has shown[1] that when a current is induced in a circular electrolytic conductor, it behaves toward induced currents in exactly the same manner as a metallic conductor of the same re-

1. *Trans.* Am. Electrochemical Society, III (1903), p. 354.

sistance. In other words, it acts as a conductor, plain and simple, and nothing associated with the experiments show in any way any deviation from the ordinary properties of a metallic conductor.

In the experiments of Richards and Landis[2] on the electrolysis of sulphuric acid solutions, such were shown to act toward feeble direct currents merely as conductors of Faraday's first class, as long as the currents used were so small that the products of decomposition were entirely recombined by the gases present dissolved in the electrolyte. In other words, to understand the phenomena presented in these experiments, the best starting point is to postulate first that the electrolyte is a simple conductor, that it conducts current in the ordinary manner which is true of any conductor, and, having this as a foundation, we may then proceed to discuss *separately,* as an entirely distinct phenomenon, the electro-chemical actions taking place where the current leaves or enters the electrolyte.

Many solid chemical compounds are conductors of electricity; in fact, the majority are. They are, in this condition, undoubtedly conductors in the ordinary sense of possessing metallic conductivity. I have found no scientist who ascribes a different kind of conductivity or a different mechanism of conduction to a solid copper bar from a liquid column of mercury. In fact, liquid mercury is used as the standard of resistance of metallic conductors. There is no sharp change in electrical conductivity when a metal melts, which again points to the identity of metallic conduction through solid or liquid metals. Similarly, there is no sharp change in conductivity when a solid conducting salt melts; it becomes a liquid conductor at the melting point without change in conductivity, just as metals do. The conclusion is that there is conductivity of the same nature in a fluid salt as in a solid salt, and as in a metal, viz., metallic conduction.

The proof of these statements may be found in any text-book of electro-chemistry, such as Ostwald's "*Lehrbuch,*" Vol. II (2d ed.) p. 716.

Since a solid salt conducts metallically, and a fused salt electrolytically, that is, with accompanying electrolysis, we must, in admitting that the mechanism of the conduction through the body of an electrolyte is mere metallic conduction and nothing else, admit also, that the electrolysis is a thing apart from the mechanism of the conduction. The electrolytic or electro-chemical phenomena

2. *Trans.* Am. Electrochemical Society, III, p. 115, and IV, p. 111 (1903).

accompanying the passage of the current are matters occurring only at the electrodes, and have no rational connection with the mechanism of the transmission of the current through the body of the electrolyte.

Much light is thrown upon this subject by the following experiment: A narrow glass tube about 12 ins. long is turned up at the ends, so as to leave about 6 ins. straight tube in the middle. It is warmed, and melted zinc chloride (M. P. 262 deg. C.) poured into it. A Bunsen burner is kept under the middle, to keep it melted, and two zinc rods are plunged into the melted salt in the upturned ends, where the salt at once sets. The cell is now constituted as follows: Zinc — Solid $ZnCl_2$ — Melted $ZnCl_2$ — Solid $ZnCl_2$ — Zinc. Asbestos screens are slipped over the tube so as to define sharply the boundary line between solid and fused salt. When the temperature is steady for some time, a thermopile is connected with the terminals, a delicate galvanometer reading to microamperes being put into the circuit. The following facts were established: (1) For e.m.f.s up to 3.5 volts, the current passing is proportional to the applied e.m.f. (2) On removing the impressed voltage, there is no trace of back e.m.f., in any case. (3) On continuing a current of 50 to 100 microamperes 15 minutes, there is no trace of electrolysis, either by the formation of gas or metallic deposit or "metallische Schliere" at the junction of the liquid and the solid electrolyte or at the metallic terminals.

The experiment proves to the writer, taking it in connection with the preceding observations, that the liquid salt acts merely as a simple conductor of the same nature as metallic conductors, and by a similar mechanism, and that the question as to whether electrolysis or electro-chemical action takes place is a matter entirely independent of the mechanism of electric conduction through the body of the electrolyte. At any rate, the passage of electric current from solid zinc to solid zinc chloride, or *vice versa,* or from solid zinc chloride to fused zinc chloride, or *vice versa,* is not one of the conditions which produce electro-chemical decomposition of the zinc chloride.

What, then, is electrolysis, and where is its seat? It is electro-chemical decomposition produced at the points where the electric current passes from a fluid compound conductor to a fluid or solid simple-conducting body or to a solid compound-conducting body, and its seat is the contact surface. Its nature or cause is entirely independent of the manner in which the electricity has

been propagated through the body of the electrolyte, and is a function only of the transfer of electricity from the fluid compound to the terminal.

This transfer of energy is accompanied by an unloosening of chemical affinities, and while one constituent of the electrolyte is liberated, the other is potentially freed. This potentially free constituent sets up through the body of the whole electrolyte a condition of chemical stress or stress of chemical affinity, which is transmitted from molecule to molecule to the other electrode, where the complimentary constituent is potentially free. This chemical stress, exhausting itself in diffusion effects, and the primary cause of the migration phenomena, is chemical in its nature and not electrical, and is *caused* by the transfer of the electrical energy at the surface of the electrodes. The migration phenomena are, in this view, secondary chemical effects of the transfer of the current energy at the surface of the electrodes, and are not, in any way, phenomena inseparably connected with the mechanism of the transfer of electric current through the body of the electrolyte.

If this view be accepted, and the writer believes it to be the correct view of the subject, then many phenomena accompanying electrolysis receive their solution. It must be understood that, in this view, the electro-chemical action is regarded as inseparable from the transfer of electric energy from a fluid compound traversed by the current to a solid or liquid conductor of chemically different nature, and, therefore, the generation of the chemical stress and the consequent phenomena of migration are inevitable consequences of the passing of the current. Viscosity by hindering the transmission of the chemical stress hinders the transfer at the electrodes, which can only proceed as the chemical stress is neutralized or exhausted by the motion of the ingredients of the electrolyte toward the two terminals.

It will undoubtedly be at once objected that the writer's view is simply that of current theories, calling electric potential stress chemical stress. Practically, the latter is to be regarded as produced by the former, in the transfer of the current at the electrodes, but the whole point of this discussion is that while electro-chemical action is produced directly by the current at the surface of the electrodes, the means of communication between the two electrodes by which the continuance of that action is preserved is in no sense by means of convection currents of charged ions, but is by means of chemical stress transmitted entirely independently of

the mechanism of the conduction of the current through the body of the electrolyte.

The conduction of the current through the body of the electrolyte is simple, normal, physical conduction, a physical phenomena; the transfer of the current from the electrolyte to the surface of the electrodes is physico-chemical, electro-chemical, the point of conversion of electrical into chemical energy and *vice versa* —it is the electro-chemical phenomenon; the reuniting of the constituents liberated at the electrodes, that is, the exchange of parts of molecules so that the compliment of the cathion finally unites by intermediate exchange with the compliment of the anion, is the effect of purely chemical stress exerted upon the electrolyte by the complimentaries of the anion and cathion, and the resulting migration phenomena are caused by, and are the result of, this chemical stress — these are chemical phenomena. The whole of electrolysis is, therefore, comprised in these three consecutive phenomena — first, physical; then physico-chemical or electro-chemical; lastly, chemical.

Discussion.

Mr. Carl Hering: I was interested in the experiment which Professor Richards described, in which he led the current from a solid salt, through a liquid and into a solid salt again; to see where the decomposition would take place, as it is an experiment I myself suggested a number of years ago, but I did not find the proper salts for carrying it out. I am very much disappointed, however, that Dr. Richards used such feeble currents as 100 microamperes, for, in my opinion, the experiment has but little value, because the amount of gas could be readily absorbed by the liquid, or be practically invisible. I am sorry he did not make the experiments with good-sized currents—10 amperes, if necessary—so that the evolution of the gas would be very decided. In that way we could find out in what part of that experiment metallic conduction ceased and electrolytic began, and *vice versa.*

Dr. E. F. Roeber: From experiments made by Professor Lorenz in Zurich, one would expect that even if Doctor Richards had continued his experiment for a longer time with the same current, the conduction would still have been apparently metallic. Lorenz shows that if the current-density is below a certain value, the metal deposited cathodically has sufficient time to go into solution in " mist " form. This mist passes to the anode and recombines with the chlorine; you have thus perfect depolarization. On the whole you do not get any effect, although you have electrolytic action. Thus the conduction is apparently metallic, although in part it is electrolytic, i. e., follows Faraday's law.

Mr. Hering: Where is the surface of the electrode? Is it the surface of the metallic rod, or the place where the solid chloride stops and the liquid chloride begins? In other words, is the solid chloride decomposed or not?

Dr. E. F. Roeber: Professor Lorenz's experiments do not give any answer to this question since he used carbon electrodes directly in the fused bath. Personally, I would expect electrolytic action at the boundary surface of the metallic zinc rod and the solid chloride. In other words, it would be surprising if the solid chloride would not conduct the current in essentially the same way as the fused chloride, although in solid state it may have, of course, an enormously smaller electric conductivity. But, of course, this question must be decided by experiments.

Dr. H. E. Patten: With regard to Prof. J. W. Richards' first point on page 4, he states that for e.m.fs. up to 3.5 volts the current passing is proportional to the applied e.m.f. For non-corrodible electrodes this would mean simply that at low *current-density* the dissolved gases or other ingredients of the electrolyte successfully remove, or depolarize, the products of electrolysis. With no polarization, naturally he would get a straight *CR* line. For his especial case, $Zn — ZnCl_2$ (solid) — $ZnCl_2$ (fused) — $ZnCl_2$ (solid) — Zn, a straight *CR* line means only that in fused zinc chloride, Ohm's law holds good. No polarization is to be expected here with zinc opposing zinc, consequently Professor Richards' second point on page 4 lends no weight to his contention. As to point 3, page 4, the current, some 0.09 coulomb, would deposit about 0.00003 gr. of zinc. This distributed over the electrode, whose size is not stated, would be hard to detect, especially as no mention is made of microscopic examination. The quantity of chlorine to be given off for this current would measure about 0.01 cubic cm and as distributed about the zinc anode would be difficult to detect by the unaided eye, especially through the coating of solid zinc chloride which surrounds this anode. With an easily corrodible anode, such as zinc, we would have certainly most, and probably all the chlorine fixed to form fresh zinc chloride.

On page 6, the conduction of the current through the body of the electrolyte is stated to be simple normal physical conduction, a physical phenomenon. Inasmuch as the other sections are discussing that very thing, as to what constitutes conduction in solids, it can not be termed "simple," although it may be termed "physical." The point is, it is hardly scientific for us to say that part of a process is physical, and leave it at that, while we explain the other part. It is for electrochemists to deal with conduction and electrolysis as a whole.

The experiments of Hittorf are interesting in this connection. He found on electrolyzing fused silver sulphide and then allowing it to cool, that metallic threads ran through the mass.

Dr. W. D. Bancroft: In this paper it is stated that many solid chemical compounds are undoubtedly metallic conductors. That would seem to be purely an assumption. Doctor Richards tries to prove it by saying that because a solid and a liquid metal conduct metallically, therefore solid salt is a metallic conductor. I do not see why he did not put it around the other way and say that because solid and liquid silver iodide conduct electrolytically,[1] then copper does. On the next page he says that "Since a solid salt conducts metallically" and then goes ahead. If you reject his assumption, there is nothing left of the

[1]Cf. Lehmann. Molekularphysik, 225.

basis of his theory. I quite agree with Mr. Hering and Mr. Patten as to the utter worthlessness of the experiment in its present form. When it comes to detecting a loss or gain of 0.03 mg zinc on the zinc rod electrodes by the eye, it is asking a good deal of us to accept that. Another point is of historical importance only. Doctor Richards says that it was shown by Thomson that Ohm's law also applies to electrolytic conductors if the counter electromotive of polarization be subtracted Since both Wheatstone and Daniell were quite clear on this point, the reference to Thomson is unfortunate.

Prof. L. KAHLENBERG: I desire to call attention to the fact that the idea that the changes of concentration of the electrolyte at the electrodes as the electrolysis proceeds is due to chemical stress or strain is not at all new. In a paper which C. J. Reed presented to the Franklin Institute a few years ago, he stated that if the products of electrolysis could be taken from the electrolyte at the electrodes without the aid of the electric current, the usual concentration changes at the electrodes would take place just as in electrolysis. Thus the deposition of zinc at the cathode would deplete the solution in zinc at that point, and consequently zinc would pass over to that place by diffusion. This view has also been held by others from time to time, and I have alluded to it in a paper on "Electrochemical Theories" which I presented to the American Electrochemical Society at its initial meeting. I quite agree with those who have spoken as to the worthlessness of the experiments described as showing that we have here a case of metallic conduction.

Prof. J. W. RICHARDS: In regard to the minuteness of the products and of the currents which I used, I will say that I very frequently use smaller currents than were used here, and the evolution of hydrogen and oxygen caused by these currents is very easy to observe; so that if there had been a trace of chlorine I am sure it would have been noticed, because of my experience with the use of currents of this kind. I can not speak with positiveness as to whether the zinc cloud produced by that current could have been seen, but I have seen it with very small currents. In regard to the use of 3½ volts, I will say that that was all the voltage I had at command at the time, and that to have caused a current of 10 amperes, as Mr. Hering suggests, would have required something like 3500 volts, and such large currents are not always available. As Mr. Patten and Mr. Bancroft have remarked, and the idea is one which I wish to impress on the Society, others have been thinking of the practical identity of the two kinds of conduction. I know that Professor Thompson and others have been working to show that ordinary metallic conduction is by a convective electronic process. The whole point of the discussion, as I take it, is that the similarity of the two kinds of conduction has been suspected, and perhaps verified, not only by this experiment, but by a number of other considerations.

The Chairman then requested Doctor Roeber to present Prof. Dr. Richard Lorenz's paper, in the absence of the author. The paper was read from the MSS. with the illustrations printed and distributed among the members.

ON THE ELECTROLYSIS OF FUSED SALTS.

BY PROF. DR. RICHARD LORENZ, *Polytechnicum, Zurich, Switzerland.*

The scientific production and the industrial utilization of the products of the electrolysis of fused salts have, during the last two decades, been greatly enhanced, partly owing to the enormous progress, which raised electrometallurgical processes to an importance at first hardly suspected, and partly owing to the researches which have been conducted with the object of studying the theory of the electrolysis of fused salts.

Pursuing the latter aim the Electrochemical Laboratory at Zurich has for some years past published a large number of researches upon the subject of the electrolysis of fused salts. The author of this paper has, in co-operation with his students, studied the phenomena accompanying the electrolysis of fused salts qualitatively as well as quantitatively both with regard to the qualitative treatment of the substances to be electrolyzed, and the determination of the amount of polarization, the e.m.f. of the current-generating fused systems, the conductivity, the voltage of decomposition, and particularly the application of Faraday's law. Based on the collection of data of facts, it was also possible to determine the outlines of a theory of the electrolysis of fused salts up to temperatures of about 1000 deg. C., and to deduce from them the consequences of the same as regards the limitations of Faraday's law, and as regards prospective technical processes.

The choice of a suitable apparatus is a constant difficulty recurring in new forms when solving electrolytic problems of fused salts. A characteristic example of this is the electrolysis of fused zinc chloride. If for instance one tries to fuse this salt in a porcelain crucible heated in a free Bunsen flame, and to electrolyze it between two carbon electrodes, no matter in what direction they project into the salt, no normal electrolysis of zinc chloride will take place. A strong evolution of gas immediately takes place, and the electrolyte shows an exceptionally high specific resistance. The contents of the crucible foams and overflows after a short time, and

zinc will not be found deposited at the bottom of the crucible, nor on the cathode, while the electrolyte itself has become strongly basic after the electrolysis. Variations of the conditions of the experiment remain fruitless. If one asks for the reason for the failure of the experiment it is to be ascribed solely to the incompleteness of the apparatus used, to which, in the case of chloride of zinc, must be added the exceptional hygroscopic quality of this salt.

It was thus very natural that the main interest of the author at the beginning of his studies should be turned toward the construction of various apparatus. An apparatus of very general application is the wrought-iron furnace intended for the V-shaped electrolyzer, which H. Helfenstein described in detail (*Zeit. Anorg. Ch.,* Vol. 23, p. 260, Fig. 2, 1900). The requirements of every such apparatus are that it be easy to operate at the best attainable constancy of temperature. The great extent to which the latter condition especially influences and determines the phenomena and results of the electrolysis of fused salts will be the subject of various explanations below. With the introduction of the V-shaped receptacle the question as to the suitable form of the electrolyzer for laboratory research was solved in a relatively simple way. Up to 700 deg. C., V-tubes of hard glass are used, above this temperature they are of porcelain. The other type to be considered is the cylindrical receptacle, whose simplest form is probably represented by the common porcelain crucible. The differences between these are of great importance for the explanation of the theory of the electrolysis of fused salts, and will be considered more in detail below.

Another question of importance, mainly in connection with the question of the current efficiency, is the way in which the electrolyte is treated beforehand. In this respect it is especially the hygroscopic haloid salts which necessitate such a preparation; among these is to be recalled more especially Bunsen's method of melting together the haloid salts of the heavy metals with the alkaline haloids, in order to be able to electrolyze them; in this way he produced low melting mixtures, which thus rendered the desired results. This method of Bunsen has been repeatedly applied and varied by other experimenters in their scientific researches, as also on the industry; and for a long time this method, which up to a certain degree is reliable, was applied to improve the current efficiency. The researches of the Electrochemical Laboratory of Zurich have for the first time shown that Bunsen's solution of the problem in some cases may be improved upon by a method never

before used, consisting of preparing the electrolyte in advance by means of water-absorbing gases. Of this process a complete description will also be given below.

The author has, partly together with his students, constructed several furnaces for laboratory use (*Zeit. f. Electrochemie,* Vol. 7, pp. 278, 279, 1900), and has published several methods of research intended for pyroelectric measurements (*Zeit. Anorg. Chem.*, Vol. 19, p. 221, 1899; Vol. 20, p. 335, 1899; Vol. 21, p. 311, 1899; Vol. 25, p. 140, 1900; Vol. 27, p. 159, 1901; Vol. 28, p. 388, 1901). In what follows there will be given some prominent examples of important phenomena and also quantitative results of the electrolysis of fused salts.

Some Prominent Qualitative Phenomena in the Electrolysis of Fused Salts.

Phenomena which are apparently abnormal are by no means rare in the electrolysis of fused salts, even to an extent that it can, on the contrary, be considered exceptional only when the electrolysis takes place according to Faraday's law. To illustrate this assertion, which is here made in a broad and general way, let us consider the electrolysis of chloride of lead, a case which even Faraday had studied. (*Phil. Trans.*, London, 1834; *Pogg. Ann. d. Phys.*, Vol. 33, p. 481, 1834; *Ostwald Klass.*, No. 86, pp. 42, 44, 65, 90, 92; No. 87, pp. 78, 86, 119, 148), and which he used for the proof of the law named after him. He succeeded in proving the validity of his law when applied to fused salts also, only by using a device which, in view of the conditions of those days, must be considered ingenious. Faraday used for the cathode melted lead, into which metal the carbon electrode was dipped. He thus avoided all those accompanying interfering phenomena and the influences tending to lower the current efficiency, which are to be mentioned later on.

When fused chloride of lead is electrolyzed, for instance, in a V-tube, it is not a matter of indifference whether a salt is utilized which has already been used in electrolysis, or whether entirely new chloride of lead is employed. In the former case one will always obtain by quantitative measurements more constant values than with fresh chloride of lead. The explanation of this fact will be given below. When the electrolysis has been carried

on for a sufficient length of time between carbon electrodes at temperatures between 600 and 700 deg. C., the cathode space has a dark color, while the anode space is yellow and clear, especially where the chlorine is developed. A black mist (Schliere) forms over the deposited lead regulus toward the anode, which mist is again destroyed by the chlorine. This mist does not consist of mechanically-loosened particles of carbon, but is a real *metallic mist* or *fog*. If the salt is heated to a higher or lower temperature, the anode space as well as that of the cathode will become a yellow-red; a layer of blask mist will then still appear, but only directly above the regulus. By using a high-current density in the electrolysis, continuous-glow phenomena appear at the anode, which are particularly troublesome in measuring the polarization and other values. The current then suddenly sinks to zero, the voltage between the terminals increases, and the carbon electrode begins to glow intensely. A sort of spark discharge takes place over the whole surface of the carbon anode submerged in the fused electrolyte, and it has the appearance as though the anode surface was going to be lifted off the rest of the electrolyte by means of an opaque gaseous stratum. A sound accompanies this phenomenon resembling that of an induction apparatus of law power. A mechanical shaking of the anode is sometimes sufficient to cause this glowing at the anode to disappear, while sometimes it disappears by itself. This phenomenon of the glowing of the anode was first observed by R. Lorenz (*Zeit. Anorg. Chem.*, Vol. 10, p. 78, 1895), later by Minet, when he electrolyzed fused aluminum chloride; by Hulin in electrolyzing a fused mixture of sodium chloride and lead chloride (*Zeit. f. Angew. Chem.*, 1897, p. 494); also by Gross (*Electrochem. Zeit.*, Vol. 4, p. 1; *Zeit. f. Electrochem.*, Vol. 3, p. 486, 1897); and by Alexander in the electrolysis of a mixture of silver chloride and silver sulphide (*Zeit. f. Electrochem.*, Vol. 5, p. 93, 1898). This phenomenon was observed in the electrochemical laboratory of Zurich by V. Czepinski (*Zeit. Anorg. Chem.*, Vol. 19, p. 245, 1899). He could observe the same phenomenon very frequently in the electrolysis of fused cadmium chloride, but only rarely in the electrolysis of the bromides of lead and silver. A fully satisfactory explanation of this phenomenon does not exist. It is always referred back to a transition resistance, caused by a layer of vapor around the anode, so that, at this electrode, the phenomenon of the Wehnelt interruptor takes place.

Let us return to the above-mentioned phenomenon of the metallic mist, the nature of which is not clear without further elucidation. It might be a case: 1), Of a real solution of the metal in its fused haloid salts; or 2), of a mere pulverization of it in suspension. In the latter case the metal would be mechanically suspended in the melted mass in the form of an extremely fine mist. This phenomenon is dependent to a high degree on the temperature and the vapor tension of the metal, respectively. With the more volatile metals it occurs at a lower temperature than with those that are volatized with more difficulty. The extension of the colored mass in the fused bath is also dependent on the temperature, so that the appearance is quite like that of diffusion. It is clear that such a phenomenon must have a most important influence on the current efficiency; and this applies to all the haloid salts of heavy and the light metals, when electrolyzed in the fused state.

The author has, in co-operation with A. Helfenstein, studied these relations quantitatively for an entire series of fused salts (*Zeit. Anorg. Chem.*, Vol. 23, p. 255, 1900). The chief results of these researches will be set forth below. The phenomenon of the mist can be produced more or less distinctly according to the temperature; at higher temperatures these mists appear and fill the melted masses more and more; at lower temperatures they condense, sink to the bottom, and the bath becomes clearer. The metallic mist which is thus produced has for most metals a very characteristic color; the zinc mist is colored a silver-white, the cadmium mist is fawn-colored, the lead mist brown-black, the silver mist completely black. The author has, together with G. Auerbach, made experiments (*Zeit. Anorg. Chem.*, Vol. 28, p. 41, 1901), which makes plausible the assumption that a real solution of metals in fused salts may exist. This solubility of the metals in the fused baths may, perhaps, have some connection with a second phenomenon, which often follows in joint action with light rays and is especially noticeable with the iodides. It can be expressed by the following equation:

$$n\,\overset{\text{II}}{M}I_2 = (n-1)\,\underbrace{M\,I_2 + M}_{\text{metallic solution}} + I_2.$$

Traces of the halogen accordingly escape without the influence of the oxygen or the humidity of the air, and there remains a saturated

solution of the metal in the fused bath. In a paper read before the Seventh General Meeting of the German Electrochemical Society (*Zeit. f. Electrochemie,* Vol. 7, p. 281, 1900), the author referred to the similarity between the relations existing here and the formation of the latent picture of a photographic plate. The phenomenon of the metallic mist has been made the subject of subsequent researches, and in a recently-published paper by S. Gruenauer (*Zeit Anorg. Chem.,* Vol. 39, p. 389, 1904) the same was even photographically recorded under particularly favorable conditions of the experiment. By means of a strong sidelight one clearly discerns the innumerable fine and minute drops of which the phenomenon of the mist is composed.

The formation of the metallic mist in the fused baths has been observed repeatedly in practice. See, for instance, F. Haber's report on the formation of metallic mists in the Hall aluminum process (*Zeit. f. Electrochemie,* Vol. 9, p. 361, 1903), but they have frequently been connected with the formation of a subchloride, or have even been confounded entirely with it. For the reguline deposit of metals from fused salt, the phenomenon of the metallic mist is very important, because such a deposit results only when the saturation of the fused bath with the metal is reached, or nearly so. In the deposition of metals the fused masses act as *depolarizers* on the cathode, which has as the further consequence that the solution pressure of the reguline metal cannot be reached during the first phases of the electrolysis, nor by using very low-current densities. When the metallic solutions and the metallic mist reach the sphere of the anode, they themselves will again act as *depolarizers* upon the halogen deposited there, as they prevent the formation of free halogens. This doubly-acting depolarizing force can rise to very high values. This may also be expressed scientifically in the following way: An electrolytic cell filled with a melted salt, in the electrolyte of which diffusion and thermal eddy currents can take place freely from the cathode to the anode, represents an electrolytic system of exceptionally high "residual current" ("Reststrom") capacity. The residual current, that is, the current whose direction is opposed to the polarization, originates from the metallic mist formed at the cathode, wandering toward the anode, where with the deposited anions it regenerates the original product by chemical reunion. The rapidity (intensity?) of this residual current depends upon the rapidity of the movement of the metallic mist through the

electrolyte, on the rapidity of the reformation of the metallic mist at the cathode, and on the rapidity of the recombination with the deposited anion. But the rapidity of the deposition of the cathions and anions is determined by the current strength used in the electrolysis. When this current strength is great, the rapidity of the deposition will exceed the rapidity of the residual current and a practical result of the electrolysis is obtained. When, on the other hand, the current strength is small, the residual current phenomenon may predominate to such a degree that a result of the electrolysis cannot be noticed. Then will arise the phenomenon of a pseudo-metallic conduction of electricity in the fused salts. These few paragraphs, which are the results of our researches extending over years, form the basis for the understanding of the electrolysis of fused salts.

Another series of phenomena present themselves to us when we consider, for instance, the electrolysis of fused chloride of zinc. There are two kinds of zinc chloride on the market, the one yielding good, the other poor, results, when electrolyzed; their empirical differences were established by R. Lorenz (*Zeit. Anorg. Chem.*, Vol. 10, p. 78, 1895), and later on by R. Lorenz in co-operation with H. S. Schultze (*Zeit. Anorg. Chem.*, Vol. 20, p. 323, 1899). By the aid of the researches of S. Gruenauer (*Zeit. Anorg. Chem.*, Vol. 39, p. 389, 1904), the author succeeded in clearly explaining the apparently very complicated relations of the electrolysis of fused chloride of zinc. The electrolysis of the above-mentioned two kinds of zinc chloride differ greatly from each other. The kind of zinc chloride which is easy to electrolyze yields gas from the moment of the turning on of the current at the anode, as well as at the cathode, without giving rise to a turbidity of the electrolyte, which will be described below. Hydrochloric acid alone escapes at the beginning of the electrolysis, while chlorine appears only gradually. The deposition of zinc begins at once on closing the current, but it was shown that the deposited zinc is dissolved at once after its deposition in the strongly acid electrolyte, consequently, as a rule, the amount of deposited zinc varies considerably at the beginning of the electrolysis. By the time the deposition of zinc becomes regular, the strong evolution of chlorine has already begun, and the electrolysis from now on proceeds "normally." Such a normal electrolysis is, however, not observed with the kind of zinc chloride which does not electrolyze well. With this kind the electrolyte, even

after only a few minutes, appears filled with an opaque mass. Hydrogen is also developed at the cathode in this case, the deposition of zinc begins immediately on closing the circuit, and at the anode chlorine is at once developed, instead of hydrochloric acid, as with the kind which yields good results. The intense cracking at the anode on closing the circuit is quite striking. It always occurs during the electrolysis of fused basic electrolytes, and is due to the pulverization of the carbons. This noise, however, ceases before the cathodic evolution of gas, and it is entirely absent in the presence of quantities of water. The anodic carbon electrodes are rapidly attacked and flow down in the form of a brown substance. Blue clouds rise at the cathode making the electrolyte impure; the electrolyte simultaneously becomes opaque by the precipitation of $Zn(OH)_2$. This substance is shown to be zinc dust formed through a pyrochemical process in a fused bath. The current can be sent for hours through such an electrolyte which has thus been made impure by zinc dust, without making it transparent. The electrolyte has a blue-gray color, until finally the turbidity begins to settle again. The carbon cathode mostly shows a tree-like outgrowth of a grey appearance, the zinc regulus itself is quite covered with the deposited substance. This deposited substance is, as mentioned before, zinc dust, a mixture of zinc oxide or zinc hydroxide with finely-powdered zinc. It is due to the fact that zinc oxide is set free by the electrolysis of an electrolyte of zinc chloride containing water, and the metal mist of zinc is condensed on it by surface action.

The kinds of zinc chloride of commerce, which may be electrolyzed with good results, contain salammoniac, while the other kinds are free from all impurities. The latter may be changed into the former by first evaporating it to dryness with a concentrated aqueous solution of hydrochloric acid, stirring constantly, and then melting it in a porcelain crucible. How, then, may the problem be solved to effectuate a normal electrolysis of quite pure fused zinc chloride, when the kind containing salammoniac is the only one yielding good results? Lorenz and Gruenauer investigated this problem, first by making up different mixtures of chloride of zinc and salammoniac and finding the results obtained by their electrolysis. It was thereby discovered that the power of the salammoniac to give off its moisture is only an incomplete one, and is also so dependent on adhering to certain definite conditions in the preparation of the electrolyte, that for this reason alone the addition of

salammoniac cannot be considered a good means for bettering the conditions of the electrolysis of fused chloride of zinc. Instead of water one has salammoniac in the bath, which has to be removed electrolytically, as set forth above, before normal electrolysis takes place. It escapes in the form of hydrochloric acid and nitrogen. The disturbing phenomena which appear in the electrolysis of fused zinc chloride depend on the fact that the water present in the fused bath brings about hydrolysis, as shown in the following equations:

$$ZnCl_2+2H_2O=Zn(OH)_2+2HCl,$$

$$ZnCl_2+H_2O=Zn\begin{matrix}OH\\ \\ Cl\end{matrix}\quad HCl,$$

$$2ZnCl_2+H_2O=Zn_2OCl_2+2HCl,$$

$$(n+1)ZnCl_2+nH_2O=ZnCl_2+nZnO+2nHCl.$$

The last equation expresses the formation of any zinc oxychloride. It is not unimportant for the electrolytic process which of these different hydrolytic separations actually prevails; for this case the above equations may be divided into two classes, namely, one in which the basicity of the bath is determined chiefly by the entrance of atoms of oxygen to the fused mass; the other, in which the basicity originates from OH groups which can be split off as OH ions. Numerous observations during the electrolysis of fused salts have led the author to the opinion that carbon anodes in particular are attacked by OH ions in a different way than by fused baths containing oxygen. The attack of the carbons in fused alkaline hydrates takes place with the formation of mellith acid products, while the discharge of oxygen disintegrates the carbon rod into splinters of carbon during the formation of CO and CO_2. What the character of the hydrolysis is with zinc chloride could not yet be determined. It must, at any rate, go back to the law of mass action when hydrochloric acid is added. This was the point of view from which the above question could be answered. Lorenz and Gruenauer for this reason turned their efforts toward the drying of the zinc chloride by means of hydrochloric acid gas, and thus obtained the actual material $ZnCl_2$ in a convenient state for electrolysis, when *certain specific conditions were observed* (the time of drying; the velocity of the drying gas current passing

through the concentrated solutions of chloride of zinc; the form of the apparatus). The carrying out of these experiments necessitated the construction of a special apparatus, the "dehydratisator." It could be shown that *even less than* 0.78 *per cent of water is sufficient* to make a zinc chloride bath yield poor results by electrolysis. The electrolysis of zinc chloride thus completely freed from water and acid will then proceed normally.

It has been shown by two examples, chloride of lead and chloride of zinc, what surprising phenomena may take place in the electrolysis of fused salts. The one salt, being absolutely free from water, shows by electrolysis in the fused state, the existence of only such interferences as arise through the residual-current phenomenon; the other salt, which is hygroscopic, and from which the last traces of water cannot be removed even by heating for hours at a red heat, is subject to interferences due to basicity of the electrolyte. But even when the causes of the latter are removed by a proper preparation of the salt before it is electrolyzed, the electrolyte thus obtained will nevertheless still be subject to the interferences caused by the residual-current phenomenon. There are thus clearly and distinctly separated from each other two phenomena which occur in manifold combination in the electrolysis of fused salts, and which can be so complicated that it was formerly considered impossible to carry out the electrolytic process with fused salt in a proper way and with a purpose, except by experience gained purely empirically.

On the Application of Faraday's Law in the Electrolysis of Fused Salts.

A quantitative treatment of the electrolysis of fused salts is possible only when the above-mentioned disturbances are carefully taken into consideration. The disturbances which are produced by the basicity of the electrolyte may be avoided if care is taken to make adequate preparation for the fusion. These disturbances, however, which are produced by the residual-current phenomenon and the development of the metallic mist, first had to be subjected to a special investigation in order to determine the precise facts. Hereupon the researches of the author, in conjunction with A. Helfenstein, give information (*Zeit. Anorg. Chem.* Vol. 23, p. 255, 1900). These may be briefly stated as follows: The residual-current phenomenon, produced by the development

and migration of the metallic mist in the electrolysis of fused salts, has, as a consequence, that the quantities liberated at the electrodes are not developed in conformity with Faraday's law. The current efficiency does not reach 100 per cent, but is less. Now all causes which tend in the direction to make the rapidity of deposition become large with respect to the rapidity of recombination of the deposited ions, due to the residual-current phenomenon, tend to produce an increase in the current efficiency. One of these causes is current strength. If, in a given apparatus, the current strength is steadily increased, then the current efficiency rises at constant temperature.

Numerous numerical demonstrations and curve sheets which were collected by Helfenstein for the electrolysis of quite different fused salts demonstrate the above-mentioned fact. Another cause of this is the form of the apparatus, its dimensions, and the position of the electrodes. When the paths in the apparatus are great, and the breadth is small, the thermic eddies which drive the metallic mist from the cathode to the anode will have a weaker action than when the path from one electrode to the other is short, and when the electrodes face each other with large surfaces. Consequently, the rapidity of recombination will be diminished for a given current and the current will increase. If, for instance, the distance between the electrodes is increased more and more in an experiment in a given V-tube, the current efficiency will increase at constant current strength and constant temperature. A further cause is the temperature. An increase of the temperature increases the formation of the metallic mist, the solubility of the metal in the bath, and also the thermic eddy movements. Consequently, the current efficiency will diminish for a given apparatus and constant current strength with increasing temperature. This occurs very rapidly so that the electrolyte strives toward a condition of pseudo-metallic conduction in such experiments also. These principles appear to me to be extremely important for the rational carrying out of industrial processes with fused salts. They give us clear indications for the construction of apparatus, for the choice of current density, temperature, etc.

But there are also specific causes of the increasing of the formation of metallic mists. One of these is the volatility of the metal. The nearer the metals are heated to their boiling point, the greater is their vapor tension, and the more will they tend to form metallic

mists. If, therefore, we deposit in similar apparatus, at the same constant temperature and with the same current strength, first cadmium and then lead, the current efficiency will be less for the cadmium electrolysis than for the lead electrolysis, because the former metal is heated nearer to its boiling point. Moreover, there are added several other specific losses to those which are determined by the residual current. These are due to the fact that the metallic mist can reach the surface of the bath. There it can be oxidized by the oxygen of the air, or when there is no oxygen the mist diffuses out from the bath and deposits itself on the walls of the vessels as a distillate. The solubility of the metals in the bath is also different, a fact which ought to be considered in quantitative experiments. After these disturbances were studied so carefully, it became possible to avoid them. The most complete avoidance of

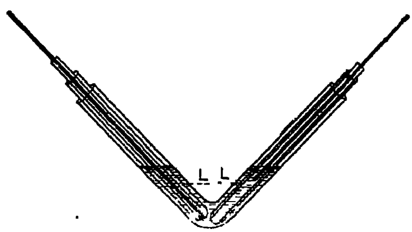

FIG. 1.— ENCASING APPARATUS.

these disturbances would consist in preventing the formation of the metallic mists.

The author, together with Appleberg, made the remarkable observation that there are substances which, when added to the fused bath, almost completely prevent the formation of the metallic mists. Owing to this observation there is opened an entirely new sphere in the theory of such auxiliary additions to the baths, which, as is well known, are so important in the industrial electrolysis of fused salts. Who does not know how important the composition of an aluminum bath is for the current efficiency in this process. Formerly it was believed that these additions served chiefly for the regulation of the fusion point and of the specific gravity of the fused electrolyte. To-day we know that under certain conditions they may be credited with a direct effect on the improvement of the current efficiency. But it is not always possible to accomplish the desired results by additions to the bath.

It remains then only to prevent the diffusion of the metallic mist. The author, together with Helfenstein, found that the nature of the metallic mists is such that they cannot penetrate through diaphragms of clay (Tondiaphragmen). The mists may also be kept together by encasing the surroundings of the electrodes. This is done by the application of the "encasing apparatus" used by Helfenstein.

The arrangement of this apparatus is as follows (see Fig. 1): The carbon cathode is first put into a closely-fitting case of highly-infusible glass, which projects out over the end of the V-tube. At the lower end of this case the carbon projects about 5 mm. The electrode, insulated in this way, is now placed into a highly-infusible test-tube of 13 mm internal diameter, which is provided with a round hole (designated by *L* in the figure) 3 mm in diameter at a distance of 45 mm from the bottom. The purpose of this hole is to establish communication between the space in the V-tube and that around the anode. The test-tube, together with the insulated electrode, is placed in the cathode branch of the V-tube. The hole in the test-tube is turned upward, so that the fused bath can circulate freely. The anode carbon is similarly encased with the exception of a few changes occasioned by the functions of the anode. As the halogen must escape from the bath into the air, a carbon electrode, 2 mm diameter, is first placed into a glass tube 8 mm inner diameter, and this again into a test-tube similar to that for the cathode; the diameter of the latter is about 15 mm. The hole is only 40 mm from the bottom; the inner glass tube, in which the anode lies freely, is broken off at the lower end into two teeth, so that it cannot rest wholly on the bottom of the reagent glass and disturb the communication between the anode and the cathode spaces. The encased anode rests with its case upon the case of the cathode.

In this apparatus Faraday's law is fulfilled under all conditions, so that one now is wholly independent of current strength, temperature, distance between electrodes, and the duration of the electrolysis. In the use of this apparatus the above-cited conditions for the adequate separation of anode and cathode spaces are fulfilled. One will be independent of the variations due to the solubility of the metals in their baths, by previously saturating the bath with the proper metals at the temperature at which the electrolysis takes place.

The diffusion of the metal vapors into the air is avoided by allowing the surface of the bath in the cathode branch to freeze. There will then be obtained almost quantitative current efficiencies, as is shown by the following curve sheet, Fig. 2:

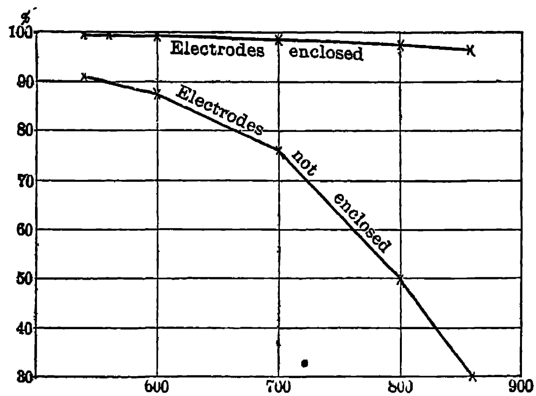

FIG. 2.—EFFECT OF INCLOSING THE ELECTRODES.

The current strength was the same for both curves. The figures which were obtained for the outputs at different temperatures are: 560 deg., 99.5 per cent; 600 deg., 99.3 per cent; 700 deg., 98.5 per cent; 800 deg., 97.8 per cent; 860 deg., 96.8 per cent. By taking into account the errors which still remain in this apparatus (namely, that the metallic mist vaporizes in the cathode space from the surface of the bath into the air and deposits again as metallic lead in the tubes), and adding to the result the losses thus obtained, one will, in fact, obtain the maximum output of 99.98 per cent, whereby the fulfillment of Faraday's law seems to be proved. The only disadvantage found in working with this encased apparatus is that the bath has a high resistance. By the use of clay diaphragms it is possible to avoid even this disadvantage without interfering with the quantitative results. In this case also outputs up to 99 per cent are obtained so that the rest is to be regarded as loss by diffusion to the outside at corresponding temperatures.

After it was thus proved by these researches that Faraday's law is fulfilled in the electrolysis of fused salts when the disturbances which are caused by the residual current are avoided, it was also proved thereby that the figures for the current efficiencies, which are obtained in the electrolysis of fused salts *without avoiding the residual current,* were conditioned only by the residual current, and

that there are no other causes. Now since this residual current, as was shown above, can be clearly defined, the idea suggested itself that it ought to be possible to represent its effect quantitatively. The relations between rapidity of the deposition and that of the recombination had to be like that of some well-defined mechanism. That this is, in fact, the case the author was able to show in co-operation with A. Appelberg (*Zeit. Anorg. Chem.*, Vol. 36, p. 36, 1903). If in a given apparatus the current strength is allowed to fall, the current efficiency falls. Finally, a point will be found where the rapidity of deposition becomes exactly equal to that of recombination. The current efficiency curve, when plotted as a function of the current strength, does not cut the axis of abscissas at the zero point of the system of co-ordinates. We obtain, then, no apparent electrolytic action, even without going to zero with the current strength. These relations have already been mentioned above, but it is of interest that they may be described mathematically by a formula which shows the current efficiency as a function of the current strength. This formula is

$$a = 100 - \frac{k}{i^n}$$

in which n and k represent constants of the apparatus and temperature, a the current efficiency, and i the current strength. This formula agrees so completely with the observations that it suffices to plot two determinations of the current efficiency in an electrolytic trough and base on them the whole series of current efficiencies at different current density which one wishes to use for electrolysis.

The following may serve as an example:

Current strength in amperes	Observed efficiency.	Calculated efficiency $n = 0.83$.
2	99.7%	99.4%
1	*98.9	98.9
0.5	97.4	98.0
0.1	93.3	92.6
0.05	84.4	86.8
0.03	75.4	79.8
0.01	40.6	49.7
0.005	*9.7	10.6

The observations marked * were used to determine the constants. The constant k is most easily obtained when the cur-

rent efficiency is determined at 1 ampere, for k is nothing else than the loss of output at this current strength.

An interesting apparent exception to the quantitative laws here presented, which apply in general to the electrolysis of fused salts, is the material PbI_2, the electrolysis of which in fused form G. Auerbach has investigated exhaustively (*Zeit. Anorg. Chem.*, Vol. 28, p. 1, 1901). Important variations in the current efficiency take place especially at 700 deg. To explain this, Faraday accepted the theory of the formation of lead tetra iodide. Auerbach's researches, however, brought forth the fact that there is no ground for this; the irregularities appear rather to be originally due exclusively to the physical properties (solubility of the metal, diffusion, etc.), with only this difference, that these disturbances are increased in the case of lead iodide. This may have its origin in the greater solubility of the iodine in the bath, as compared with chlorine, and seems to show that the part taken by the anions in the disturbances in the electrolysis of fused salts has not yet been clearly shown.

It remains now to consider the quantitative relations at the anode in the electrolysis of fused salts. Upon this point Auerbach, in the Electrochemical Laboratory at Zurich, found quantitative proofs. If a fused salt is electrolyzed in a given apparatus, always under the same conditions as to temperature and current strength, one can be sure to invariably get the same current efficiency for the metal within the limits of error. The residual-current phenomenon presents itself so exactly that for certain conditions of experiment there will result a certain loss by recombining. It should be almost self-evident that, as the loss of metal arose through a recombining with the anion, for instance chlorine, the loss at the anode should consequently be exactly as great. But no one had as yet determined the amounts which appear at the anodes in the electrolysis of salts. So when we began our researches we were astonished to see that the current efficiencies in the electrolysis of fused lead chloride were not identical at the cathode and at the anode. But when the electrolysis was continued long enough they became so. It was, therefore, shown that there was a time phenomenon in the current efficiency at the anode.

In the first stages of the electrolysis, the current efficiency at the anode for chlorine is lower than that of the lead at the cathode, and rises gradually up to it. The excess of chlorine loss over the

lead loss is due to the fact that the carbon anode saturates itself only slowly with chlorine. As soon as this saturation of the carbon anode is complete, the efficiency of the chlorine becomes the same as that of the lead. Carbon anodes which have already been used show a more rapid rise in the chlorine efficiency; an equality of the anodic and cathodic efficiencies is, therefore, reached sooner than with new carbon anodes. The process in the electrolysis of fresh chloride of lead with weak currents is consequently understood to be that a part of the separated chlorine is absorbed by the carbon rod at the beginning of the electrolysis, and that a further part which is equivalent to the loss in lead efficiency is regenerated to lead chloride by the metal solution, and only the remainder escapes as free chlorine. An addition of oxide of lead to the chloride of lead during the electrolysis has no effect on the cathodic efficiency, but on the other hand no chlorine is disengaged at the anode and the carbon rod becomes oxidized by the escaping oxygen. Electrolytes containing oxygen pulverize the anode carbon, as has already been mentioned above, while in electrolytes which are free from oxygen the anode carbon is refractory toward chlorine.

In what follows some further information is given on e.m.f's and polarization.

E.M.F's and Polarization in the Electrolysis of Fused Salts.

The counter e.m.f's which arise in the electrolysis of fused salts were determined by R. Lorenz together with V. Czepinski (*Zeit. Anorg. Chem.*, Vol. 19, p. 208, 1899); by O. H. Weber (*Zeit. Anorg. Chem.*, Vol. 21, p. 305, 1899); and by R. Suchy (*Zeit. Anorg. Chem.*, Vol. 27, p. 152, 1901). They measured the polarization by the discharge through a galvanometer of high resistance (method of polarization discharge), but repeatedly controlled the values thus obtained by combination of chains of fused salts. In this way there were determined, among others, chains of the type of the Daniell cell, which will, however, not be further considered here. It was found that the polarization was dependent on the appearance of the metallic mist in quite a similar way as the current efficiency is, and, therefore, also on the form of electrolytic trough used. In an electrolytic trough in which the metallic mist can diffuse from the cathode to the anode, the polarization will be less when an appreciable effect is exercised on the anodic potential as soon as the

metallic mist reaches the anode. The e.m.f. of chains in which the metallic mist reaches the anode appears to be reduced quite considerably in contradistinction to one in which this is not the case. The metallic mists must be considered as powerful depolarizers when they arrive at the anode. This fact could be observed in an experiment with the above-described encasing apparatus (Fig. 1). As was mentioned, the anode and cathode are here surrounded by various encasing tubes of glass, so that the respective anode and cathode spaces communicate only through small holes with the main mass of electrolyte which acts as an intermediate space. If one observes in such a trough, which is filled for instance with fused chloride of lead, the polarization discharge by means of a galvanometer of high resistance (galvanometric voltmeter) after

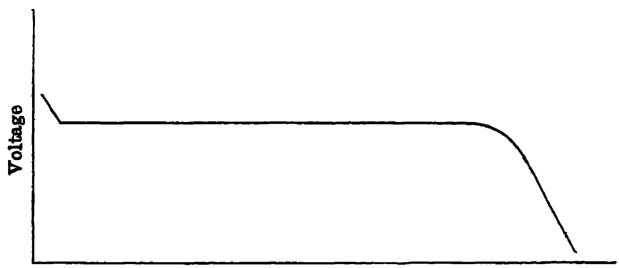

FIG. 3.—POLARIZATION CURVE.

the electrolysis has proceeded for some time, the curve thus obtained will have the form of a discharge curve of an accumulator.

There will be observed in the galvanometer a long continuing, constant deflection of about 1.2 volts at about 600 deg. C. which then gradually diminish when the electrodes become poor in polarizing material. If the anode branch of the tube is kept completely filled with chlorine gas and is protected from the atmosphere, such a deflection may, under circumstances, last for hours. When the system has been in a complete state of repose for so long a time, it can happen that a cloud (Schliere) of metallic mist flows out of the hole in the encasing around the cathode. This cloud then spreads out gradually into the middle space of the electrolyte and in spreading out in various directions it also extends to the hole in the case around the anode. But from the anodic hole a more or less thick cloud then by chance flows down into the anode space.

All these processes have up to this point no effect on the steady and completely stable position of the galvanometer needle. But at the moment when the cloud of metallic mist in its wanderings arrives at the carbon rod anode, and touches it, the deflection of the galvanometer will fall suddenly almost 0.6 to 0.8 volt, and the needle will swing to and fro with irregularity. Simultaneously the cloud in the anode space will be seen to become pale; it becomes consumed under the influence of the contact action of the pole by the chlorine present there, that is, it is changed into chloride of lead. In order now to prevent a further crowding of the metallic mist into the anode space one could cut off the cloud up at the cathode hole by slightly turning the encasing tube, so that the hole is placed in a clear part of the electrolyte which is free from the mist. The turning of the encasing tube has no effect on the galvanometer deflection, but the mist which is there then becomes completely clear due to the excess of chlorine in the anode space, and the electrolyte again becomes as before, honey-yellow and clear. As soon as this point is reached *the deflection in the galvanometer again rises to its original value of* 1.2 *volts,* and remains there as usual until the system is completely discharged. There is found in such a case the following discharge curve (Fig. 4):

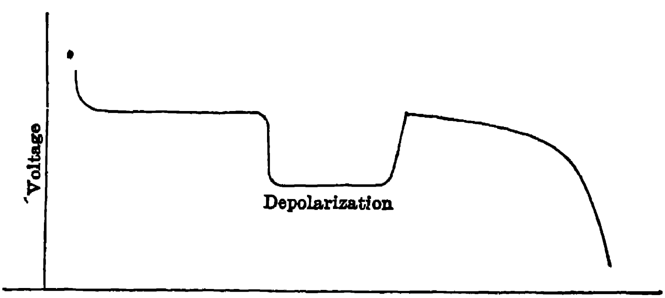

FIG. 4.— POLARIZATION CURVE.

It follows from this that one must proceed with care in the selection of the conditions of the experiment in making such polarization discharge curves. As Czepinski has shown, one no doubt obtains polarization values in the usual V-tube, but they will be too low on account of the depolarizing action of the metallic mist at the anode. In fact O. H. Weber could prove the connection between the resulting formula and the apparatus used, in which the more or

less strong depolarization is a result of the above-described phenomenon. He obtained in this way the following interesting curve sheet (Fig. 5), in which he plotted the constant discharge point as a function of the temperature.

In this the curve 1 represents the polarization for chloride of lead at different temperatures, as measured in the following apparatus. At the bottom of a wide porcelain tube, which contains the fused bath, there was a *large* amount of lead regulus, into which dipped a carbon rod well insulated from the rest of the bath by means of a porcelain tube. The anode, also a carbon rod, was in a straight tube open at the bottom,

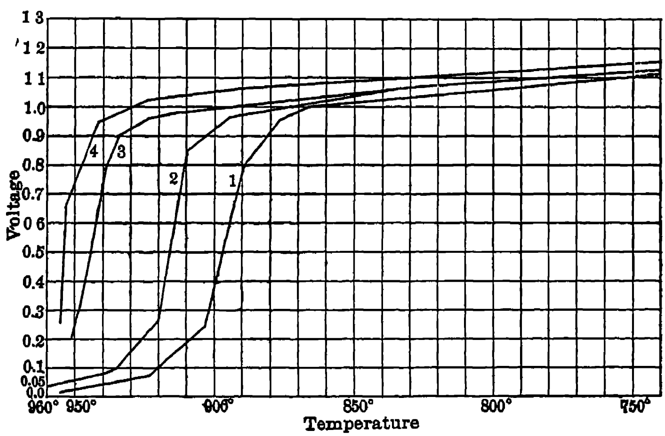

FIG. 5.— POLARIZATION CURVES.

which dipped into the bath from above and ended not far above the lead regulus. If the anode be now moved away from the regulus, and inclosed more completely by its porcelain tube, curve 2 will be obtained for the polarization values. The anode was furthermore put into a V-shaped tube which had a short and a long branch. The short branch was dipped into the fused bath. By this a marked separation of the anode space is accomplished, and curve 3 is obtained. If, finally, the lead regulus is also placed into such a V-shaped tube, whereby a complete separation of the anode and cathode spaces is accomplished, curve 4 will be obtained. Each one of the successive curves indicates higher polarization values and a smaller temperature coefficient

of polarization than the preceding one; this is true as well in the range of lower temperatures in which the eddy motions are limited (but in that case with smaller variations), as also at high temperatures at which the eddy motions are still active even with a better separation of anode and cathode, and in this case with very strong variations. Just as with the encasing the current efficiency also approaches more and more to that required by Faraday's law as was shown above, so will the normal polarization be reached thereby when Faraday's law is fulfilled, and, therefore, it may be said: *The polarization phenomena in the electrolysis of fused salts are analogous to the current efficiency phenomena.*

The best determinations of the polarization at different temperatures which were obtained in the most appropriate apparatus refer to the electrolysis of chloride of lead, chloride of zinc, and chloride of silver. The chloride of lead chain can be represented by the formula $E^t = 1.2818 — 0.000584$ ($t = 506$ deg.) according to O. H. Weber (*Zeit. Anorg. Chem.*, Vol. 21, p. 305, 1899). Furthermore, the chloride of zinc chain by: $E_t = 1.662 —$ 0.000751 ($t = 430$ deg.) according to .R. Suchy (*Zeit. Anorg. Chem.*, Vol. 27, p. 152, 1901). These formulas become possible because the temperature coefficient for these two combinations are constant over a long range of temperatures, which for the chloride of lead chain are between 506 deg. and 890 deg., and for the chloride of zinc chain between 430 deg. and 660 deg. For the chloride of silver chain the temperature coefficient at a low temperature is not constant; it becomes so only at higher temperatures. The Gibbs-Helmholtz formula $U = 2.23041 \left(E — T\frac{dE}{dT}\right)$ can be applied to these polarization values, which enables us to connect the combination heat of the current producing processes with the free heat of formation.

In the following tables E are the e.m.f.s of the chains, $\frac{dE}{dT}$ are the temperature coefficients, U are the values of the total energy, A is the external energy, $U — A$ the changes in the total energy comparable with the heats of combination calculated from thermochemical data which are given in the next to the last column; the last column contains the differences U (electric) —U (thermic)

(C) Pb | $PbCl_2$ | Cl_2[C].

t	E	$-\frac{dE}{dT}$	U	A'	$U - A' = U_{el.}$	$U_{therm.}$	Δ
956	0 2784	0 1298					
955	0 4082	0 1231					
953	0 6545	0 0291					
947	0.8293	0 0183					
942	0.9209	0 0119					
937	0.9806	0 00246					
927	1 0052	0 00245					
917	1.0297	0.00114					
890	1.0604	... ...	80.164	2.326	77.838	Constant $= U_{18^\circ} + S_{Pb} - S_{PbCl_2} = 83.770 + 1.161 - 5.806 = 78.1555$ Cal.	—0 317
857	1.0812		80.232	2.260	77.972		—0.163
837	1.0938		80.275	2.220	78.055		—0.100
817	1.1058	Average of the temperature coefficients from 506—890° $\frac{dE}{dT} = -0\ 000584.$	80.294	2.180	78.114		—0 041
767	1.1320		80.155	2.080	78.075		—0.080
747	1.1427		80.109	2.040	78.069		—0.086
727	1.1536		80.072	2 000	78.072		—0 083
707	1.1641		80.017	1.960	78.057		—0.098
667	1.1830		79.809	1.880	77.929		—0 226
657	1.1878		79.763	1.860	77 903		—0.252
637	1.2008		79.823	1.820	78.003		—0.152
617	1.2173		80.048	1.780	78.268		+0.113
607	1.2233		80.054	1.760	78 294		+0.139
577	1.2398		80.008	1.700	78 308		+0.153
572	1.2428		80.012	1.690	78.322		+0.167
562	1.2488		80.017	1.670	78 347		+0.192
547	1.2557		79 933	1 640	78.293		+0.138
537	1.2612		79.915	1.620	78 295		+0.140
527	1.2663		79.906	1 600	78 306		+0.151
506	1.2818		80.030	1.558	78 472		+0 317
..	. ...	0.0007404	......	.....	......	....	......
502	1.2847		85.629	1.550	84 079	83.931	+0.148

Temp	U	A	$U - A - U_{el.}$	U_1 therm	U_2 therm.
450°	100.93 Cal.	1 45	99 48 Cal	97.59 — S	99 03 — S
500°		1.55	99 38 "	97.46 — S	
550°		1.65	99.28 "	97 39 — S	
600°		1.75	99 18 "	97.27 — S	
650°		1.85	99.08 "	97.16 — S	

$Ag \mid AgCl \mid Cl_2$ (Carbon).

Temp	$E.M.F$	$\frac{dE}{dT}$	U (Cal.)	$A=\frac{RT}{2}$	$U-A$	U therm.	Δ
480°	0.902		24.00	0.75	23.25	28.14 $-S$	$-(4.90-S)$
		0.0002					
490°	0.900		23.98	0.76	23.22		
		0.0002					
500°	0.898		24.21	0.77	23.44	28.11 $-S$	$-(4.67-S)$
		0.0002					
510°	0.896		24.23	0.78	23.45		
		0.0002					
520°	0.894		24.64	0.79	23.85		
		0.0002					
530°	0.892		25.61	0.80	24.81		
		0.0002					
540°	0.890		25.61	0.81	24.80		
		0.0003					
550°	0.887		25.61	0.82	24.78	28.00 $-S$	$-(3.22-S)$
		0.0003					
560°	0.884		25.55	0.83	24.72		
		0.0003					
570°	0.881		25.90	0.84	25.06		
		0.0002					
580°	0.879		26.33	0.85	25.48		
		0.0004					
590°	0.875		26.69	0.86	25.83		
		0.0003					
600°	0.872		27.10	0.87	26.23	27.93 $-S$	$-(1.70-S)$
		0.0003					
610°	0.869		27.72	0.88	26.84		
		0.0004					
620°	0.865		28.61	0.89	27.72		
		0.0004					
630°	0.861		29.70	0.90	28.80		
		0.0005					
640°	0.856		28.70	0.91	27.79		
		0.0004					
650°	0.852		29.72	0.92	28.80	27.84 $-S$	$-(0.96-S)$
		0.0006					
660°	0.846		29.70	0.93	28.77		
		0.0004					
670°	0.842 Average error ±0.001						

For the two first-named chains it is an unusually remarkable fact that the temperature coefficient is constant over a long range of temperature. The author has endeavored to account for the meaning of this fact by means of a thermodynamic calculation. If the equation $A-U=T\frac{dA}{dT}$ is differentiated for T, it gives $\frac{dA}{dT}-\frac{dU}{dT}=\frac{d\left(T\frac{dA}{dT}\right)}{dT}$. This gives $-\frac{dU}{dT}=T\frac{d^2A}{dT^2}$. If now $\frac{dA}{dT}$ is constant, then $\frac{d^2A}{dT^2}=0$, and, therefore, $-\frac{dU}{dT}=0$, hence $U=$ constant. As long as the temperature coefficient does not change with the temperature, the heat of combination of the reaction is

constant. But the general thermodynamic formula for the action of the total energy, according to which we recalculate these for different temperatures, is as follows:

$$U_t = U_{to} + S_1 + S_2 + \dots + m_1 \int_{to}^{t} c_1\,dt + m_2 \int_{to}^{t} c_2\,dt + \dots$$
$$- S'_1 - S'_2 - \dots - m'_1 \int_{to}^{t} c'_1\,dt - m'_2 \int_{to}^{t} c'_1\,dt \dots$$

In this equation:

m_1, m_2, m_3, represent the molecular or atomic weights of the reacting components;

m'_1, m'_2, m'_3, the molecular or atomic weights of the products of the reaction;

c_1, c_2, c_3, the specific heats of the reacting components;

c'_1, c'_2, c'_3, the specific heats of the products of the reaction;

S_1, S_2, S_3, the sums of the molecular fusion and vaporization heats of the reacting components;

S'_1, S'_2, S'_3, the sums of the molecular fusion and vaporization heats of the products of the reaction;

U_t the heat of combination at the temperature t, and U_{to} that at the temperature t_0.

From this it follows that U_t is constant when

$$m_1 \int_{to}^{t} c_1\,dt + m_2 \int_{to}^{t} c_2\,dt + \dots\dots m'_1 \int_{to}^{t} c'_1\,dt - m'_2 \int_{to}^{t} c'_1\,dt$$

equals zero or a constant. In every case it follows from this equation by differentiation:

$$m_1c_1 + m_2c_2 + \dots\dots - m'_1c'_1 - m'_2c'_2 - \dots\dots = 0.$$

For a binary compound, therefore

$$m_1c_1 + m_2c_2 - mc = 0$$

that is, the molecular heat of the product produced is equal to the sum of the atomic heats of the reacting components. But U might also have a value which is not absolutely constant but only approximately so, and we may write:

$$m_1 \int_{to}^{t} c_1\,dt + m_2 \int_{to}^{t} c_2\,dt - m \int_{to}^{t} c\,dt = E\varphi(t).$$

In this expression E is a small quantity. It shows that there is only a small dependence on the temperature. It then follows after differentiating that

$$m_1c_1+m_2c_2-mc=E\varphi'(t)$$

and the latter expression is also very small whereby a law similar to the one above given follows again. If it be remembered, moreover, that the following reaction always exists

$$m_1+m_2=m$$

it follows that

$$m_1c_1+m_2c_2=(m_1+m_2)c$$

or that the specific heat of the product produced is

$$c=\frac{m_1c_1+m_2c_2}{m_1+m_2}.$$

The so-called thermochemical rule of mixtures, therefore, also applies, with a very close approximation, to the specific heat for the systems which were investigated.

In the adjoining tables for chloride of lead and chloride of zinc a small, but nevertheless very definite, range in the variations of the calculated values of the heat of combination from those observed indicates that the regularity here found is not an absolute sharply defined one. The change in the specific heat of the reacting components, lead and chlorine, is rather greater than that of the material produced, lead chloride. Nevertheless, the slight bend which the curve of the e.m.f's shows toward the temperature is so small that it is preferable to assume the regularity here shown and to place the algebraic sum of the specific heats involved equal to zero, when one calculates the action of the total energy from the heats of combination.

In closing this section attention is called in a few words to the fact that in the polarization of fused salts a time phenomenon also develops. If the polarization discharge is observed in the electrolysis of a fused salt, for instance, lead chloride, in an electrolytic trough in which the anode and cathode spaces are not separated from each other by a great distance, the galvanometer indicates for the discharges only an extremely short normal dis-

charge point. If the polarization (measurements?) be now repeated continually, the discharges being observed repeatedly during the test, the constant discharge point will become longer and longer, until finally there will result a nearly normal discharge curve having the appearance of the one drawn above. This phenomenon, observed by Sacher (*Zeit. Anorg. Chem.*, Vol. 28, p. 385, 1901), and by Auerbach (*Zeit. Anorg. Chem.*, Vol. 28, p. 1, 1901), is again completely analogous to the relations of the current efficiencies at the anode, and indicates here, as it does there, the degree of saturation of the carbon rod with chlorine. When the carbon rod still continues to absorb chlorine, the capacity of the electrode is small and the discharge point short. When it is saturated the discharge curve becomes normal and Faraday's law is fulfilled at the anode, as has already been shown above.

The researches of the author with J. F. Sacher have brought out very interesting polarization discharge curves for fused sodium hydrate. It was found that there was a double fall in these discharge curves (like that which has lately been shown frequently for various accumulators in which the plates are not of lead). One of the constant discharge points was at 2.14 to 2.18 volts, the other at 1.3 to 1.1 volts; this corresponds to the charging of the cathode on the one hand with metallic sodium, on the other with hydrogen, opposite to an anode which is charged with oxygen. It was interesting to verify these polarizations in the reverse way by plotting the curve of decomposition voltages. The author, together with Sacher, carried this out for iron as well as for platinum chlorides, whereby they studied and recorded the required preparation of the iron electrode for this purpose (passive state of the iron). The plotting of the curve of decomposition voltage showed that the point of the discharge of hydrogen disappeared when the fused bath is completely free from water, so that the pure sodium hydrate is electrolytically decomposed entirely into sodium at the cathode and into oxygen (discharge of OH ions) at the anode.

The decomposition curves were taken at two electrodes of the same size, as well as at a large anode and a small cathode, and at a large cathode and a small anode. Iron and platinum electrodes were used. The results obtained for the decomposition voltage agree completely with the polarization values so that the meaning of the decomposition point is thereby made completely

clear. In the following table the results of the researches are collated:

Method.	1st point.	2d point.
Polarization discharge	1.3—1.1	2.14—2.18
Two equal electrodes	(1.1)	2.23—2.25
Large anode, small cathode	1.15—1.16	2.06—2.09
Large cathode, small anode	1.33—1.31	

The proof that hereby water was formed at the anode was subsequently supplemented to the work of Lorenz and Sacher by Le Blanc and J. Brode (*Zeit. f. Elektrochemie,* Vol. 8, p. 717, 1902).

The effect which the formation of metallic mist has on the deposition of the alkaline metals is expressed in the work of R. Lorenz and W. Clark (*Zeit. f. Elektrochemie,* Vol. 9, p. 269, 1903). They succeeded in depositing potassium from fused potassium hydrate by encasing the cathode.

In concluding this review of our knowledge to the present date in the sphere of the theory of the electrolysis of fused salts, the author desires to express the wish that the industries may make advantageous use and draw useful conclusions from it.

Especially in the United States of America extended use is made of the electrolysis of fused salts. Besides the larger processes, like the aluminum process which has been in operation a long while, many experiments are also made to apply the electrolysis of fused salts to new industrial applications. Perhaps some one or other of the features explained above may prove to be of use in practice.

There being no discussion on the paper, the Chairman requested Dr. Bancroft to present Prof. Dr. W. Ostwald's paper, in the absence of the author.

ELECTROLYSIS AND CATALYSIS.

BY PROF. DR. W. OSTWALD, *University of Leipzig.*

The chemical result of the conduction of an electric current through an electrolyte is made up of two very different effects, namely the phenomena of the *conduction* through the electrolyte and those concerned with the *transfer of electric charges* at the electrodes. With respect to the first effect, we have clear and definite conceptions, based on the universally confirmed theory of Hittorf. According to this theory, the mechanism is of the greatest simplicity, namely, the cations and anions migrate in opposite directions and with mobilities which depend mainly on the specific nature of the ions, but also on the solvent, the concentration and the temperature. The process which results in the second effect — namely the ionic discharge or the general transfer of charges at the electrodes — also seemed at first to be simple and clear. But the assumption that the ions which accomplish the transportation of the current through the electrolyte are also the materials which undergo the electric change at the electrodes, could not be supported; it was the recognition of the very fact that both can be different, which made possible the development of the proper explanation of the phenomenon of electrolytic conduction itself. Berzelius still based his electrochemical system on such an incorrect conception of the electrolytic phenomena. He at first and chiefly tested the salts of the alkaline metals and earths; since *bases* and *acids,* besides hydrogen and oxygen, result from their electrolysis, he regarded the former two substances as the real constituents of the salts, and based his entire chemical system on this misconception derived from his experiments. Even Faraday held rather erroneous views in this regard, though we owe to him the name and conception of the ions. The first one who was consistent was *Daniell,* who throughout assumed the metals to be the cations of the salts. This scientist's conception of the mechanism of the transportation of electricity by the ions was still imperfect, and it was Hittorf who then worked out the theory in this respect and reduced it to a perfectly simple and clear one; to him we owe

the statement that electrolytes are salts, and the experimental methods for determining the nature of the ions in every given case, as also the ratio of their migration velocities independently of any possible electrode reactions.

The new idea of decisive importance was that of a *secondary reaction*. While by the conduction of the current through the electrolyte a certain ion may be transferred to the cathode, it does not necessarily follow that it is deposited or liberated there. In a solution of potassium chloride it is undoubtedly the potassium ion which transports the positive electricity to the cathode. Yet it does not appear there as the product of electrolysis, but in its stead, potassium hydroxide and hydrogen are formed. This is explained by the conception that directly or primarily potassium is deposited, which, however, cannot exist in contact with the water of the solution and reacts with it, forming potassium hydroxide and hydrogen.

First of all, this view enables us to conceive the same simple mechanism for the conduction of the current through an electrolyte, in the two theoretically fully analogous cases of the electrolysis of the salts of heavy metals which do not decompose water, and the electrolysis of the salts of light metals which decompose water, although both cases are apparently quite different from an experimental point of view. Another result is that the apparent contradiction to Faraday's law is avoided which, in the case of electrolysis of salts of light metals, could be found in the fact that, besides the liberation of oxygen and hydrogen, the formation of acid and alkali appear as immediate effects of the electrolysis. Finally our view gives an explanation of the fact that in some cases, instead of the secondary reactions, it is possible to get the primary products by means of a slight modification of the conditions of the experiment. For instance, in the case of the alkali metals this is possible by the use of a mercury cathode.

In the course of time the necessity has manifested itself to consider a great many reactions as secondary. The best known example is the decomposition of water between inert electrodes. Since water itself is a poor conductor, alkali or acid is added, and in former descriptions of this method it was stated that these additions are made only for the purpose of rendering the water a "better conductor." Now we know with sufficient certainty that the conduction of the current is really accomplished by the ions of the additions, and, in the case of an acid, we consider the oxygen

developed at the anode as the result of a secondary reaction between the discharged anion and the solvent water, while in the case of an alkali, we must assume secondary reactions even at both electrodes, namely at the cathode the reaction between alkali metal and water and at the anode the change of the discharged hydroxyl ions into oxygen and water.

By the development of modern electrochemistry our views on these questions have been modified so as to be more precise. If at an electrode several processes are possible by means of which the transfer of electricity from the electrolyte into the electrode may take place, we have to assume that that reaction will take place for which the potential difference is a minimum. Or in other words, if we gradually increase the e.m.f. applied at the terminals of the cell, beginning with zero e.m.f., then, of all possible ionic discharges, those will first occur which require the smallest potential difference.

However, the potential difference for any electrode reaction has in general no constant value, but depends upon the temperature and to a considerable degree upon the *concentration;* the range of the strongest influence is exclusively at *low* concentrations. If we start from "molar" solutions and increase the concentration, we cannot go beyond 10 times molar concentrations for experimental reasons, because more concentrated solutions of electrolytes cannot in general be prepared. Within the limits mentioned, the maximum possible difference is about 0.06 volt for the electrolytic production of any constituent of these solutions out of the concentrated or out of the dilute solution. On the other hand, if we start again with molar solutions and decrease the concentration, the same difference of e.m.f. (0.6 volt) is found for every decrease of the concentration to one-tenth its former value; hence for 0.001 molar solutions compared with molar ones, it has already increased to 0.17 as a maximum, and for 0.000001 molar solutions it is twice as great. For infinitely dilute solutions it is theoretically infinite, but experimentally one does not exceed two volts.

The following important conclusion may be drawn herefrom. If there are several possibilities for the reaction at one electrode, the chemical reaction which really occurs depends not only upon the nature of the possible chemical reactions, but also upon the concentration of the substances which are present, and by suitably varying the latter we can bring any reaction to any point in the voltage series.

Now it is a universal fact that the electrolytic process itself results in a decrease of the concentration of that substance in the neighborhood of the electrode which is involved at that moment in the electrode reaction. Hence any such reaction has the tendency to stop by itself and to be replaced by that reaction which can and will take place as the next one with increasing voltage. Moreover, since the voltage is influenced only by the concentration *at the electrode itself,* not by the average concentration in the whole electrolyte, this "polarization" would necessarily take place almost instantaneously after the current has begun to flow, if there were not other processes which bring the exhausted kind of ion again in sufficient quantity to the electrode.

These compensating influences are of a twofold kind. First, we have diffusion which tends to make good any decrease of concentration with a force proportional to the existing concentration difference. Secondly, we may have chemical reactions which are caused by the exhaustion of the electrolytically changed ions, since the equilibrium which had been disturbed by their disappearance begins to reconstitute itself and, therefore, also tends to counteract the loss. Both compensating processes, however, start only after the loss had been established, and are, therefore, never able to reproduce the original condition. The result is always a polarization, i. e., an e.m.f. which counteracts the applied e.m.f.[1]

The value of the e.m.f. of polarization evidently depends upon the final decrease of concentration of the electrolytically changed ion. For this purpose we have to consider the stationary condition which is reached after the first variable processes have terminated. For the case in which the compensation for the exhausted ions is accomplished by diffusion only. Helmholtz has already given the underlying principles of the reaction. These may be briefly summarized as follows:

The current causes a consumption of the active ion at the electrode surface, the quantity consumed being proportional to the quantity of electricity which has passed. But the electrolytic migration of the ions does not bring as many new ions to the cathode as are consumed; it brings only a certain portion of this number, this portion being given by the ratio of the migration velocity of the active ion to the sum of the migration velocities of

1. There are known a few cases of abnormal polarization in which the current causes an e.m.f. of polarization of the same direction as the applied e.m.f. their theoretical explanation is possible on the basis of the theory given in what follows.

both ions. Hence there must necessarily result ionic exhaustion which is counteracted by diffusion. The exhaustion progresses so far until diffusion — which simultaneously increases on account of the increasing concentration difference — brings back to the electrode exactly the missing amount of ions in the form of its salt. There will, therefore, be produced finally a certain distinct concentration difference between the electrode surface and the main part of the solution, and there will be a corresponding distinct e.m.f. of polarization. Since the diffusing quantity of salt is proportional to the coefficient of diffusion and to the *difference* of concentration, while the e.m.f. of polarization is proportional to the *ratio* of the concentrations, it follows that with the same current density the e.m.f. of polarization must become the greater the lower the total concentration of the active ion.

These considerations hold good directly for primary electrolysis in which the current is transported by the same ion which undergoes the change of concentration at the electrode. For secondary electrolysis we have only to consider what the influence of the current will be, according to Faraday's law, upon the concentration of the electrolytic ion at the electrode. Let us consider, for instance, the case of "water decomposition," and let us distinguish the two cases in which, for increasing the conductivity, an acid or a base is added. With an acid solution we have to consider at the cathode the concentration of the hydrogen ion and we then have primary electrolysis. At the anode we had to consider first the concentration of the anion, for instance the SO_4 ion. By its reaction with water, oxygen and sulphuric acid is formed according to the equation

$$SO_4'' + H_2O = H_2SO_4 + O,$$

i. e., this process yields sulphuric acid which disintegrates again into its ions. The concentration of the SO_4 ion is, therefore, not diminished but increased, and this increase corresponds exactly to the decrease of the concentration at the cathode. Diffusion will now carry away the sulphuric acid from the anode and this will lead to a stationary condition. The total result is not a compensation of the two e.m.f's. of polarization at the electrodes, but since an *increase* of concentration has a smaller influence on the potential than an equal *decrease*, we will ultimately have a polarization in the ordinary sense, i. e., the passage of the current is rendered

more difficult, and this will be the case to a greater extent the higher the current density and the smaller the total concentration.

If a caustic potash solution is electrolysed, we have a similar increase of the potassium hydroxide concentration at the cathode, due to the ionic migration, since it is not removed there from the solution, and we thus have here quite similar conditions as exist for sulphuric acid near the anode. At the anode we have, in the case of caustic potash electrolysis, the reaction $2OH' = H_2O + O$. The concentration of HO is approximately proportional to that of the potassium, but the latter decreases on account of the migration of the ions. Furthermore, immediately at the anode a layer of pure water is formed. The total result in this case is again a polarization in the ordinary sense.

All these considerations are based, however, upon the further supposition that *the chemical reactions by which the secondary products are formed occur with a speed which is infinitely great in comparison with the other processes.* This is a supposition which, while very approximately fulfilled in the cases which we have considered, yet is not necessarily fulfilled in all cases. If we have to do with reaction velocities which are not infinitely great, there arise a great many new questions which we had no need of answering so far.

It may be asked, for instance, whether at the anode in a potassium hydroxide solution, the secondary reaction $2OH = H_2O + O$, or even $4OH = 2H_2O + O_2$ occurs, or whether we do not have a primary reaction, namely the discharge of bivalent oxygen ions. True, the existence of such an ion O'' has not yet been proved; it can never exist in considerable quantities, because it soon reacts with water according to the equation

$$O'' + H_2O = 2OH'$$

and forms hydroxyl ions. On the other hand, one may state that it must always be present in very small quantities wherever hydroxyl ions are present, since the above reaction also takes place in the reverse direction, as read from the right to the left hand of the equation, and the simultaneous concentrations of the two kinds of ions are determined by the (unknown) equilibrium constant of this reversible reaction. As long as this reaction also takes places with a speed which is infinitely large compared with that of the electrolytic processes, it does not matter which reaction is assumed, since no measurable quantity is thereby influenced; it is, therefore, not possible to decide which of the different possible

reactions really occurs and a discussion of this point does not fulfill any useful purpose.

Let us now imagine the possibility of rendering the reaction between hydroxyl ions and bivalent oxygen ions infinitely slow by some means. It would then be possible to decide which of the two reactions occurs at the electrode (under the supposition that it is either the one or the other). If it is the hydroxyl ion which is discharged, the decrease of concentration, produced by a given current, will have a relatively much smaller effect than an equivalent decrease of concentration of the oxygen ion which is present in a much smaller concentration. Under equal conditions we would, therefore, get a small polarization in the first case and a very strong polarization in the second case; and by measurements of the polarization we could decide which of the two reactions really takes place.

Such means of changing the speed of a given reaction within very wide limits really exist in chemistry in what is called *catalyzers.* From this it is at once evident what a very essential and important part the catalyzers are able to play in electrolytic action. By retarding one of the possible reactions by means of a negative or retarding catalyzer, we are able to *exclude* its influence from the electrolytic process. By accelerating by means of a catalyzer a reaction which is of itself slow, we can *include* it in the electrolytic process. In other words, we are no longer compelled to let the current act in the way stated by the above simple law, but, in principle, we are now able, *by applying suitable catalyzers, to prescribe to the current that reaction which we want to have to take place,* and it does not matter at which point of the voltage series this reaction is situated.

This fundamental idea may be applied in two directions. First in *synthetic* work; if we suppress by negative catalyzers those reactions which would take place before the desired one, we can bring the desired reaction to the front; or if the reactions which take place before the desired one occur with a low speed, we can accelerate the speed of the desired reaction by means of a positive catalyzer and can thus produce the same effect. The second application is *for analyzing the reactions which really take place at the electrodes.* If these reactions are essentially influenced by a certain addition, and if we know the single reaction which is altered catalytically by the addition, we can conclude that this reaction takes an essential part in the electrode process. If a catalyzer of known

specific activity does not influence the electrode reactions, we can draw the reverse conclusion and state that that reaction is not a part of the electrode process.

In connection with this, it should be emphasized that what is called above briefly *the electrode process* is in reality a rather complex phenomenon. In the simplest case — for instance, in the primary electrolysis of a silver salt — this reaction consists in the change of the silver ion to metallic silver. But "metallic silver" is not a well-defined substance, since we know elementary silver in very different allotropic states. Here the very general rule manifests itself that a system, when changing from one state to another one, first assumes the unstable intermediate states which change step by step into the more stable ones; in the case of explosive antimony, detected by Gore, it is well known that one of these states remains metastable for a longer time. One may say, therefore, that the first product in the cathodic deposition of silver is that which is formed as the next step from the silver ion after the loss of its positive charge, i. e., silver dissolved in water, probably of the molecular weight of Ag. On account of the presence of white metallic silver the silver cannot continue to exist in this state, but changes into the stable form of white silver. At the cathode a distinct proportion of dissolved silver ions to dissolved silver metal will, therefore, be established, and this proportion will determine the potential by means of an equation similar to that given by Peters[2] for the potential of a mixture of ferrous and ferric salts. The greater the speed of the change of dissolved silver into the white solid metal, the smaller will be the concentration of the dissolved silver metal and the more it will approximate that which is given by the self-solubility of white silver[3] and which, therefore, represents the equilibrium potential of a silver electrode.

Similar considerations hold good for the secondary reactions at an electrode. Thus, as the primary anodic product of the electrolysis of dilute sulphuric acid, a substance SO_4 may be assumed which reacts with the solvent water with any (probably very high) speed, to form oxygen and sulphuric acid. In the case of concentrated sulphuric acid which contains mainly the ion $H'SO'_4$, it is not the substance HSO_4, but its polymerisation product $H_2S_2O_8$

2. *Zeit. f. Phys. Chemie*, v. *26*, p. 200, 1898.

3. Such a solubility must be assumed in any case. This follows from general reasons and from the facts, detected by Naegeli, of the accumulating poisonous action, the "oligodynamics" of water in contact with metallic silver.

which is obtained, or its ions, as the conceivable primary product. If, however, the anode has too strong catalytic properties, for instance, if it consists of a large platinum plate, the persulphuric acid which is formed soon disintegrates into sulphuric acid and oxygen, and the unstable intermediate product does not remain.

It will thus be seen that even the simplest electrode reactions are made up of a plurality of reactions following each other step by step. Since each of the same can be influenced catalytically, it is already evident that a very great variety of results is possible. We should furthermore consider that many of the unstable substances which are formed as intermediate products during electrolysis, and which quickly disappear, are not yet known separately with respect to their properties, and especially with respect to the action of catalyzers upon the same. Under these circumstances it will be evident what an abundance of peculiar and unexpected phenomena we may hope to detect in this way, and how much new knowledge we may expect to obtain from a systematic investigation of this field. The literature of electrochemistry already contains a great number of separate facts which are not only understood more easily but applied with greater safety, if considered from the points of view given in this paper (a large portion of which was suggested by other scientists, since, about six years ago, I emphasized the necessity of taking into consideration catalytic action in the investigation of the phenomena of electrolysis). I regret that I cannot go into details; I wish to remark only that for some time Prof. Luther with his scholars has attacked this problem from different sides; the papers already published by them, and still more the unpublished investigations, will show the generalty and variety with which this scientist has understood developing this principle and rendering it useful.

The Chairman: If there are no remarks upon this paper of Dr. Ostwald, it will be published in full in the *Transactions*.

I should like to take this occasion to congratulate the Section on the attendance and the character of papers we have had for the last three days, and to say that we have now concluded the list of papers assigned to Section C of the International Electrical Congress.

There being no further business before the Section, the Chairman declared it adjourned.

TRANSACTIONS

OF

SECTION D

Electric Power Transmission

Honorary Chairmen, M. PAUL JANET and ING. A. MAFFEZINI
Chairman, MR. CHAS. F. SCOTT
Vice President, ING. E. JONA
Secretary, DR. LOUIS BELL

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Section D was called to order at 11:35 a. m., Monday, September 12, 1904, Chairman C. F. Scott, presiding.

CHAIRMAN SCOTT: The first paper available is by Sig. E. Bignami, entitled "Electrical Transmission Plants in Switzerland." The paper is in manuscript in the Secretary's hands. I have asked the Secretary to be good enough to give us an abstract of the paper.

SECRETARY BELL then gave an abstract of the paper of Sig. Bignami, which follows:

ELECTRICAL PLANTS IN SWITZERLAND.

BY ENRICO BIGNAMI.

Although Switzerland has not produced even so much as a handful of coal, it possesses, nevertheless, in the rivers that spread over its surface in every direction, and in the glaciers of its Alps—in those white watery bodies, which, like fantastic seas, hang, as it were, suspended between heaven and earth—rich, nay inexhaustible, mines of hoüille blanche—"white coal."

The initiative early taken by private parties in the generation of electrical energy from water-power was soon followed by the civil authorities, and many towns, after vesting the service of light and traction in the municipal government, have, on their their own account, established hydro-electric plants of great importance; and the practice of utilizing hydraulic powers is likewise spreading among the municipal systems of the various cantons.

The canton of Fribourg, which took the initiative, will soon have plants representing more than 10,000 kw; the canton of the Grisons is now engaged in carrying out a plan for exporting electrical energy to Italy (to the amount of 20,000 kw); the canton of Zurich has asked for Government assistance for the creation of an artificial lake to provide water for a plant of 20,000 hp. In the first stage of a project looking forward to the utilization of 60,000 hp, the government, following the example set by the towns and cantons, is beginning also to enter the field, after having bought up almost all the railroads in the country, with a view to purchasing all eventually. It encourages, on the one hand, experiments in electric traction by private agencies, and, on its own account, has begun to collect statistics of all the water-powers in the confederation and to prepare a law according it first right over all water-powers which can be utilized in transforming to electric traction the system of state railroads.

The first step will be followed by others, and some there are who declare that the state should assume ownership of all water-

powers not in private hands, whether belonging to towns or cantons, in order to control, produce and distribute electric energy in the most advantageous way. They maintain, in short, that electric power should be produced without intermediaries, brought to the centers of consumption, and sold at the cost of production.

The electric railway for Bernina (Engadine) is an experiment in electric traction of considerable interest. Curves of 40 metres radius and inclines of 7 and even 8 per cent were adopted for this project; the former were made possible by a track of a meter gauge, and by the design of the rolling stock to be used on the line; the latter have become practical and economical only through the application of electric traction.

Switzerland, especially in the North and in the Northwest, is literally teeming with both large and small central-station plants, which, together with their ramifications, enclose it in an almost uninterrupted network of electric wires. But while the plants producing electricity in Switzerland were on the 30th of last June 550 in number, those distributing power, and which, consequently, possess more or less extensive branches, urban and interurban, and in and between cantons, were only 266, almost all of which are brought into mutual relation by the Union of Swiss Electric Central Stations, located in Zurich. Of these 266, we may class 60 per cent as principal plants, and the others as secondary plants. Altogether they represent a rated capacity of 180,000 kw, which may be considered as increased 10 per cent by the boiler reserves and storage batteries with which a third of the central plants are provided. On the 30th of last June the principal stations numbered 162, and the secondary stations 104, making a total of 266.

If one understands by the capacity of a plant that which the station itself can actually give with existing apparatus, then the principal stations represent a capacity of 169,920 kw, distributed as follows:

148 stations with water-power, or 92% of the total capacity.
5 stations with steam-power, or 3% of the total capacity.
9 stations with gas-power, or 5% of the total capacity.

The 104 secondary stations possess altogether about 9000 kw; thus making a total of 178,920 kw for both principal and secondary stations.

As for the different types of stations, those operated by water-

power have increased from 96.5 per cent to 97.5 per cent; those with steam and gas power from 7.5 per cent to 8 per cent.

The relative number of gas engines and steam engines has changed but little; gas engines are, in general, employed, as before, by the smaller stations, while steam engines are utilized by a limited number of the larger stations, a result brought about by the amount of average power, which is in the case of stations with gas engines, 180 kw; of those with steam engines, 500 kw; of those with hydraulic power, 700 kw; and for all together, 660 kw.

So far as systems of current are concerned, we have, of the 162 principal stations, 95 with alternating diphase or triphase current; 55 with continuous current, and 12 with both continuous and alternating current. Of the secondary stations, 70 employ alternating, mono- or polyphase current; 24 employ continuous current, and 10 employ continuous and alternating current. Among the 162 principal stations, we find, besides the 14 employing steam or gas engines, 25 stations utilizing not only water-power but also gas or steam engines, as reserve for an eventual lack of water, or for any conceivable interruption of service. Of these 25 stations, 18 have steam engines, 5 have gas or oil engines and 2 have engines of both kinds. The normal capacity represented by the 25 plants is 25,000 kw for water-power and 10,000 kw for the engine reserves. These reserves show progress in the utilization of water-power.

The idea of a reserve is beginning to spread also to secondary stations, and 18 of them possess gas engines and one a steam reserve.

Almost all the principal and some of the secondary stations, belong to the Union of Swiss Electric Central Stations; and in the proof sheets of one of the tables of statistics now being printed for its annual report, 1904-05, are contained considerable data concerning 120 plants. These data furnish us with information of the most detailed character, although they do not apply to all the 120 stations alike. For instance, in the case of change of plant due to variability of hydraulic power, we have data for only 90 stations. These data refer to maximum and minimum power. The former represents 140,000 kw; the latter, 85,000 kw, i. e. 60 per cent of the maximum power.

As regards improvement of the condition of power by means of storage (hydraulic or electric), we can draw no sure conclu-

sions. We know, however, that some stations have increased their storage batteries and that others have introduced new storage batteries.

For storage batteries, we have data referring to 30 stations, for which we find generators, 10,000 kw; storage batteries, 4200 kw-hours, or 42 per cent of generator capacity for one hour.

As to the number, size and power of engines or prime movers, in the statistics of 120 stations we find 77 with 230 turbines aggregating 110,000 kw; 25 having some steam engines, or steam engines alone, aggregating 11,000 kw; 18 having some gas or oil engines, or gas engines alone, aggregating 4500 kw. For stations which have been considered in last year's report, we find an increase in turbines from 100,000 to 110,000 kw, or 10 per cent; an increase in steam engines from 10,500 to 11,000 kw, or 5 per cent; an increase in gas and oil engines from 3500 to 4000 kw, or 14 per cent.

It is especially to be noted, moreover, that in the case of 82 plants, having a normal capacity of 100,000 kw, we have with the aid of turbines 113,000 kw; the average power of turbines is 400 kw; of steam engines, 300 kw; of gas and oil engines, 10 kw. The greatest power is 1300 hp for turbines; 1000 hp for steam engines, and 380 hp for gas engines.

We find 16 rotary substations containing in all 42 machines, representing a total capacity of 5000 kw, and showing a considerable increase in comparison with last year. The average power of the machines is 320 kw.

Of the 120 plants, 108 possess electric generators in the proper sense of the word. The greatest capacity represented by the generators is 600 kw for continuous current and 870 kw for polyphase current. The increase of power in the case of generators is 32 per cent for continuous current, 28 per cent for monophase, 32 per cent for polyphase, and 30 per cent, on an average, for all systems of current.

It should be noted that the highest voltage directly produced is 2,250 volts for continuous currents, and 10,400 for alternating.

Of the 68 plants with alternating current here considered, 66 have transformer substations aggregating 1630 transformers, or 24 on an average per station. The greatest number is found at the stations of Montbovon, 92; Geneva, 78; Grande Eau, 76; Kubel, 75; Olten-Aarburg, 68. The larger city stations possess numerous substations, Zurich having now 58.

The transformers now number 3,400, or 50 for each station. The greatest number is found at Geneva, which has 480; Montreux, 240; Olten-Aarburg, 185; Rathhausen, 160; Zurich, 120; Montbovon, 115; Lucerne, 110. The highest average of capacities of transformers are at the plants of Beznau, 110 kw; Kander, 75; Eaux-et-Forets, 56; Kubel, 35.

In comparison with the preceding year, the increase in the number of transforming stations is 25 per cent; for the transformers themselves, 30 per cent; for the capacity of all transformers (from 67,000 to 109,000) 40 per cent.

According to the statistics of the Union, the systems of current are divided as follows:

Alternating, monophase, 33 cases, or 44 per cent.
Alternating, diphase, 7 cases, or 9 per cent.
Alternating, triphase, 29 cases, or 38 per cent.
Series continuous current, 4 cases, or 5 per cent.
Parallel continuous current, 3 cases, or 4 per cent.

As for the systems of distributing current used in the installation of motors, we find for 68 cases, or 65 per cent, alternating current; or specifically, monophase, in 24 cases, or 25 per cent; diphase, in 6 cases, or 7 per cent; triphase, in 38 cases, or 33 per cent; and for 48 cases, or 35 per cent, continuous current, as follows:

Two-wire systems, 20 cases; three-wire systems, 28 cases; 16 stations have two or three different systems of current.

For distribution of light, with alternating current, we have for the monophase system, two-wire, 16 cases; monophase system, three-wire, 28 cases; diphase system, 3 cases; triphase system, 20 cases. For the continuous current, we have 8 cases of two-wire and 28 cases of three-wire system.

Sixteen stations have also two systems of distribution of current for illuminating purposes. About half the stations, namely, 50, have different systems of distribution for motors and illumination.

As regards power for distribution of light, the 120 stations furnish us with 100 cases thus divided:

Voltage: 100-105, 110-115, 120-125, 150-160, 200-210, 220-240. A voltage of about 120 volts is most generally employed.

As to voltage of transmission, here again we must observe an evident increase, for at the present time one plant (Beznau) em-

ploys 25,000 volts; two plants (Kander, Vernayaz) employ 16,000 volts; one plant, (Lac de Joux) employs 12,500 volts, and one (Kubel) employs 10,000 volts. Then we have eight with 8,000-10,000 volts, all with alternating current. For continuous current we find one plant with 23,000 volts (St. Maurice, Lausanne); one plant with 14,400 volts (Combe-Garot-La Chaux-de Fonds). We find the highest pressure not in a public, but in a private plant, that of the Oerlikon Works, with 25,000-30,000 volts, alternating current.

As for the frequency of the alternating current, we see a continuous improvement. For the principal plants we have:

Cycles per second.	Cases.	Total.
38, 43, 45, 46, 48	1	5
42	3	3
53	2	2
60, 65, 70	1	3
40	15	15
50	40	40

It is to be observed that the frequency of 50 cycles per second is becoming more general.

The statistics, which we have endeavored to make more complete by the data furnished us by friends, show that the 90 stations to which these data apply possess in all 65,000 wooden poles, or 97 per cent; 1,200 openwork iron poles, or 1.7 per cent; 700 supports on buildings, or 1 per cent.

In the aerial circuits of 100 stations, we find 32,000 wooden poles, or 80 per cent; 8,000 supports on buildings, or 20 per cent.

As regards the crossing of railroads by wires, we find in the case of transmission lines, that 108 out of 120 stations considered, there are 240 crossings, or 67 per cent, above railroads; 118 crossings, or 33 per cent, under railroads. These last crossings are those of highest tension. Almost all these transmission lines have lightning arresters of the horn type. Of distributing wires we find 290 crossings of low-tension wires, or 73 per cent, above railroads and 110, or 27 per cent, under railroads. We have then, in all, 530 crossings, or 70 per cent, above railroads and 228, or 30 per cent, below.

The stations considered serve 720 localities. Those serving the greatest number are: Montbovon, 58, 3,800 kw; La Goule, 32,

1,500 kw; Hagneck, 31, 3,600 kw; Châtel St. Denis, 25, 400 kw; Kanderwerk, 26, 4,500 kw; Kubelwerk, 24, 2,200 kw; Geneva, 22, 13,000 kw; Rheinfelden, 11 (besides 15 outside of Switzerland), 11,200 kw; Lac de Joux, 20, 5,000 kw.

The territory provided for by the 120 stations is inhabited by 2,300,000 people; and for the stations considered in the statistics of the preceding year, we find an increase of from 1,000,000 to 1,300,000.

The stations which provide for a greater number of inhabitants are, Zurich, 160,000; Geneva, 120,000; Bâle, 118,000.

As regards the development of the transmission lines, it should be observed that 80 out of the 120 plants considered have in aerial wires a total length of 2,800 km, and in underground wires a total length of 240 km; so that the total length is 3,240 km.

The greatest lengths are found for the plants of: Kander, 245 km, 4,000 kw; Montbovon, 220 km, 3,800 kw; La Goule, 150 km, 1,500 kw; Hagneck, 130 km, 3,600 kw; Beznau, 120 km, 5,400 kw; Lac de Joux, 80 km, 5,000 kw. Besides these, 12 plants have a length of line between 50 and 110 km. The maximum distances of transmission are also on the increase, for instance, St. Maurice, 60 km; Montbovon, 55 km; Kanderwerk, 52 km; Beznau, 42 km; La Goule, 36 km.

Also, for 12 stations the maximum distance exceeds 20 km length of line. We have an average for the 120 stations possessing transmission lines 14 km as the greatest distance. For those in operation the preceding year this average was 13 km.

As regards distributing networks, 90 stations have 1,500 km length of line in aerial wires, and 30 stations have 460 km length of line in underground wires. The greatest lengths are as follows:

	Aerial wires.	Underground wires.	Total.	Power.
Montbovon	160 km	0 km	160 km	3800 kw
Geneva	84 "	83 "	167 "	13,000 "
Sihlwerk	84 "	0 "	84 "	1200 "
Zurich	1 "	68 "	69 "	2500 "
Berne	15 "	58 "	73 "	1200 "
Bâle	0 "	70 "	70 "	1200 "
Les Clées........	58 "	0 "	58 "	1200 "

As to the relation between the capacity of the station and the output, we have data only for 79 stations, which represent one-

half of the power of all the stations considered in the statistics of the Union. In these stations we find employed for illuminating purposes an amount of power equal to 680,000 lamps of 50 watts each — 34,000 kw; for heating apparatus, 2,200 kw; for motors, 33,000 kw; total, 169,200 kw.

Comparison with the development of the preceding year shows that the percentage has increased both in the case of motors and for illuminating and heating distribution.

The normal output of this group of stations is 80,000 kw; the average utilization is therefore only 88 per cent of the capacity; but for the whole of Switzerland this figure will probably be larger, for some of the principal stations are not included in the group considered. It will perhaps amount to 100 per cent, and one might consequently draw up the following approximate data for all the stations of Switzerland (kw 178,920):

For lighting, 53 per cent, or 90,000 kw; apparatus for heating, 3 per cent, or 5000 kw; motors, 44 per cent, or 75,000 kw. Total, 170,000 kw.

For motor service we have the following figures: Of the 120 stations, 20 have motors in service only outside of illumination hours; 31 have motors which may be utilized at all times, including illumination hours, and 62 have motors of both kinds. The number and power of these motors is as follows: 4,500 motors, 39,000 kw, in service at all times; 2,700 motors, 8,200 kw, in service only outside of illumination hours; in all, 7,200 motors, 47,200 kw. The average power of motors which may be employed at all times without restriction is 9.5 kw; of motors which can be used only in the daytime, 4.6 kw.

The greatest average power of the motors is found in the stations of Zurich, 140 kw; Linthal, 110; Beznau, 100. The minimum average power is at Sissach-Gelterkinden, 0.4 kw; Le Locle, 1 kw; Geneva, 1.2; Olten-Aarburg and Neuchatel, 1.4.

The greatest demand of all lamps burning simultaneously is 70 per cent, or 22,500 kw, while the motors restricted to daylight service require 100 per cent; consequently, the maximum power of the latter represents one-third of that used for illumination purposes, while the preceding year it represented one-fourth. One finds an increase of considerable proportion at Burgdorf (440 per cent); at Rheinfelden (210 per cent); at Eaux et Forets (116 per cent). Several stations begin to attach greater importance

to the use of current for heating apparatus, so that considerable increase is found at St. Gall (224 per cent); Bâle, rural district (205 per cent); Grande Eau (160 per cent); Birseck (110 per cent); Biel (120 per cent); Burgdorf (100 per cent). The greatest percentage for increase in capacity is found at Brugg, 58; La Chaux-de-Fonds, 38; St. Gall, 30 ;Bâle, 32; Birseck, 24.

It should be noted here that the stations named are not new, but have existed for many years; and one finds an increase of more than 10 per cent in a number of stations, equal to one-fourth the total number.

For the stations considered here, the number of customers on the 30th of last June was, for motors used only during daylight, for 82 plants, 1,500 subscribers; for other motors, for 80 plants, 3,000 subscribers; for illumination, for 120 plants, 42,000 subscribers; for heating apparatus, for 70 plants, 3,000 subscribers. The average installations are, for lighting, 18 lamps of 50 watts each; for heating apparatus, 0.95 kw; for daylight motors, 4 kw; for other motors, 13 kw.

Electric meters for ampere-hours and watt-hours for continuous current are employed in 40 stations, with an increase of 22 per cent; for single-phase alternating current, in 50 stations, with an increase of 32 per cent; for polyphase alternating current, in 30 stations, with an increase of 16 per cent. Time dials are in 34 plants, or 22 per cent.

Many plants have increased the number of their electric meters, such as Rheinfelden, 120 per cent; Burgdorf, 96 per cent; Brugg, 65 per cent; Hagneck, 65 per cent. Even in time dials it should be observed that there is an increase of 150 per cent at Coire; 100 per cent at Berne and Oerlikon, and 75 at Burgdorf. But the number of time dials has, in general, diminished to 22 per cent of the total number of meters, which fact must be attributed to the progressive diminution in the price of electric meters.

In the utilization of energy with relation to maximum capacity and annual consumption, we have data for only 15 plants, not all of the most important. The data are as follows: Maximum activity of plants in motor current, 3,800 kw; current for illumination, 4,400 kw; total, 8,200 kw.

The annual activity of these 15 plants would give a total of 18,000,000 kw-hours, which would correspond to 1,380 hours of complete annual utilization; to 2,350 hours activity with maximum power, and 1,830 hours activity with normal power.

For the 15 stations we have the following distribution:

MOTORS.	Lighting (per cent).	Joint service (per cent).
For actual power in kw, 39 per cent.......	61	100
For maximum power, 50 per cent........	57	100
Annual power in kw-hours, 64 per cent....	36	100

The data of 50 stations here considered show 7 with a coefficient of utilization of power above 0.9 and even as high as 1.0; and 8 others with a coefficient of 0.8 and as high as 0.9. Only 5 stations have a coefficient below 0.5; the 30 others go from 0.5 to 0.8.

The stations with 80 per cent, or more than 80 per cent, utilization of their power are midway between the small and medium-sized employing, however, as much as 1,500 kw. In general, we have a utilization of activity somewhere in the neighborhood of 70 per cent.

We shall define coefficient of utilization of possible energy as the ratio of the effective activity of a station in kw-hours to that which would have been possible by using full power. The stations for which we have this coefficient are 24 in number; and the coefficient, in the case of two-thirds of the stations, varies between one-tenth and two-tenths, and is high only for one-third. For 5 stations it is as high as 50 per cent and even 55 per cent. The latter constitute stations which are specially situated, and conditioned by various factors which influence the utilization, *e. g.*, special tax on meters, and prices fluctuating according to season (Zug); many motors restricted to operation in the daytime and during the summer season (Sihlwerk, Les Clées); combination of the most intense light with the maximum of water and so forth. But, in general, these figures prove that the utilization of energy annually possible is still less than it should be, and so it will remain so long as the methods used up to the present day are adhered to. It is then of the utmost importance to seek a means of obtaining a higher percentage of utilization, and the solution of the problem will have to be sought, on the one hand, in a wider application of means of storage, and on the other, in new methods for the useful consumption of energy.

Nine-tenths of the installations of Switzerland have been made, in so far as the materials of electric tràction are concerned, by the following large Swiss firms: Brown, Boveri & Co., of Baden (Argovie); Ateliers de Construction d'Oerlikon (Zurich); Société de l'Industrie électrique et de la Mecanique (Geneva); Société

d'Électricité Alioth de Muenchenstein (Bâle); Schweizerische Wagonsfabrik de Schlieren (Zurich). The same may be said of the installations now in process of construction. It may be added that the transformation in the traction system of the principal railroads of Switzerland—which have been already bought up by the confederation, or will be purchased in a short time — will be accomplished by these great houses, which are now engaged in experimenting on their own account, being encouraged and financially assisted in these experiments by the federal government. Among these experiments, those recently made with great success between Oerlikon and Seebach by the "Usines d'Oerlikon" are specially noteworthy.

The turbines for hydraulic installations have almost all been furnished by Swiss houses, especially the following: Escher-Wyss, of Zurich; Societe Anonyme d'Électricité, formerly Rieter & Co., of Winterthur; Piccart, Pictet & Cie, of Geneva.

The operation of public and private plants, especially with respect to the safety of both personnel and public, is regulated by the Techanical Inspectorate of the Swiss Society of Electricians. This inspectorate, which is subject to the committee of supervision of institutions controlled by the association, has been financially aided by the state to the amount of 40,000 fr. a year, beginning in February 1893, — the date when the law relative to electric installations of both low- and high-tension current was carried into effect. The observance of this law is entrusted to the care of the same inspectorate, to which all requisite authority has been granted.

One may say that the projected plants are innumerable. Noteworthy, particularly, is the one now being studied for the government of the canton of Zurich (60,000 hp); that of Poschiavino and of the water-power of Val Bregaglia in the Grisons of 50,000 hp. a part of the power of which is to be exported to Italy; and of the Rheinfelden Society, which has drawn up for the town of Bâle a project for two plants, to be situated on the Rhine, of 15,000 hp each. The canton of Tessin also proposes to export electric energy to Italy, after having secured from the state the right to employ water-powers still unused, following in this the example of the canton of Fribourg. The Chambers of the Confederation, on the other hand, have appointed a commission to draw up a law which gives to the federal government the right of preference over all water-powers which it may need for electric traction on the railroads of the state.

DISCUSSION.

Chairman SCOTT: A frequency of 50, it may be remarked, has been selected by the British standards committee, and proposed for the standard for Great Britain, with 25 as a lower frequency.

Dr. LOUIS BELL, Secretary: And to that the Secretary should add that 50 was the frequency of the first four or five polyphase plants installed in this country and afterwards the frequency was raised to 60, under, I suppose, the idea that the old high-frequency transformers could be used to advantage by not cutting down the frequency too far. Everybody who tried them came to grief, but although they came to grief the frequency was still persisted in, so that we have the curious and anomalous condition in this country of having a frequency of 60 largely used for lighting and power and 25 instead of 30 as a common frequency for the large power plants.

Chairman SCOTT: The paper which has been presented strikes me as one of particular interest in many ways. It shows the very general use of electrical energy from water power in Switzerland, where there are probably more water-powers per square mile, and where civilization is present for utilizing these powers, to a greater extent, than is perhaps the case anywhere else. The large number of installations in the relatively small country, the variety and the types of apparatus used, as given by these statistics, offer us a good view, and make a valuable paper for a congress of this kind as showing the status and present condition of work in Switzerland. I think that some of the points brought up may suggest others to you, and I would be very glad to have any discussion upon this paper.

Dr. F. A. C. PERRINE: In comparing Swiss work with work in this country, one of the most notable features is the high value of the load factor. There are only five stations of the entire list in Switzerland in which the ratio of the average to the maximum power is less than one-half, and there are five stations mentioned in which the average is above nine-tenths of the maximum. In this country I know of but one station in which the average is as high as nine-tenths of the maximum, and there are a considerable number of stations in this country where the load factor is not over thirty per cent. That indicates in Switzerland a very intelligent user as well as a very careful manager of stations. A large number of motors are mentioned in this paper as being operated entirely outside of the peak hours of the load; comparatively few station managers in this country have been able to induce their customers to realize the importance of the power from water to them sufficiently to induce them to accept a contract which insisted on their keeping entirely off the peak. The voltage of transmission in reference to the distance of transmission seems to be lower than that used in this country. The longest transmission is about fifty miles, and the highest voltage about twenty-five thousand volts. That gives 500 volts per mile, and one would judge from hearing the statistics, that the average in Switzerland was considerably less than 500 volts per mile. Here, according to the statistics presented by the Transmission Committee of the Institute, the average voltage seems to be

about 600 volts per mile, and running up to about 1,000 or more. It is also remarkable that Switzerland has at least four direct-current distribution plants, and in one of these the voltage runs up to 3,000 volts and in one to 14,000. The plant of that character has disappeared entirely from this country, although the first long-distance transmission plant that was installed in this country, so far as I know, was of this character, installed by Mr. N. S. Keith in California. In general, our engineers have believed that it was more disadvantageous to take care of the high-potential commutator than to meet such disadvantages as may occur with the alternating-current distribution. The very small average power from the motors is also noticeable. If I remember correctly, the average power is considerably less than ten horse power. In this country, while we have not the excellent statistics that are obtained by this Swiss society, observation would lead one to infer that the average is considerably higher, and the maximum of power for motors much greater. We have in considerable numbers cases at least as high as 1,000 kw per individual motor, Another noticeable feature seems to be that in such a small country as Switzerland, they have not used the obvious advantage that would come from the inter-communication and inter-connection between plants. In this country, the plants that are commercially the most successful, are those having more than one generating station, and in which the generating stations are inter-connected, running in parallel and aiding each other. In a few parts of this country this has been done even by rival plants. In fact, the longest transmission that has ever been used practically was where, on account of accident to a station, power was bought from a rival, and transmitted 296 miles for a considerable period during the rehabilitation of the station damaged. This advantage of the inter-communication of water-power stations has also reduced the relative importance of the steam auxiliary which is so marked in these Swiss examples. The large amount of power in reference to the size of the country is notable and the complete utilization of all possible water-power are the most striking things to an American mind in reading these Swiss statistics.

Chairman SCOTT: Can Mr. Hutton give us the total length of circuits which are connected together into one general inter-connected net-work; also the maximum distance over which power is transmitted?

Mr. R. S. HUTTON: I haven't those figures accurately. As I remember, the total length of the transmission circuits of the California Gas & Electric Corporation is approximately 700 miles. The two largest stations, as connected by the circuits, are about 300 miles apart. These, when tied in parallel, would not of course represent the total length of transmission of 300 miles, but there have been occasions where one plant, being somewhat disabled, the length of transmission has been somewhat in excess of half the distance between them. Not only have these plants been tied in parallel, but several others are feeding in at various points along the line, generating, not only at different voltages, but at a different number of phases, which are made so that they can be paralleled by transformation.

Chairman SCOTT then read his address to the Section.

ELECTRICAL POWER TRANSMISSION.

BY CHAS. F. SCOTT.

The national and international expositions held in America mark certain fairly definite eras in electrical development.

In 1876, at the Philadelphia Centennial, the telephone was announced. There was a dynamo which could supply one arc lamp. One of the features of the exposition was a great engine of 1000 hp.

In 1884 an electrical conference was held in Philadelphia. By this time electric lighting was assuming commercial significance. There were numerous stations supplying arc lights and incandescent lights. Some of these were beginning to pay dividends, marking the passage of the electrical industry from the experimental to the commercial stage. Generally speaking, however, the apparatus was crude and inefficient, there were few stationary motors, the railway motor and the alternating current had no commercial significance.

By 1893, the year of the Columbian Exposition at Chicago, electrical matters were assuming an extended engineering and commercial development. Engine-type generators for alternating and direct current were being introduced. The street-railway motor was just beginning to operate cars heavier than the ordinary street car, although the principal thoroughfare in New York city was starting a cable road. Electrical exhibits were in great prominence at the exposition, but, in looking back over a decade, the most striking feature is that certain things which are now so common were there simply as exhibits.

The rotary converter was a curiosity in 1893. It began its commercial work a few years afterward and did not become a very important element in electrical systems until four or five years later. In a discussion upon power transmission at the Electrical Congress held that summer, an electrical engineer from California made this statement: "I wish to say definitely that to the investor in California to-day, the successful machine for long dis-

tance transmission of power electrically exists only in the minds of the inventors and promoters, or in some beautiful advertisement." There had been in operation for a few years a single-phase transmission of about 200 kw at 10,000 volts a distance of less than 30 miles for lighting. There were a few plants transmitting power by single-phase synchronous motors at voltages of about 3000. Although polyphase generators were in use, there was no plant transmitting polyphase current at high voltage. I remember distinctly a friend announcing to me during the Congress that it had just been officially determined to use polyphase alternating current instead of direct current for the Niagara Falls Power Company. The contract for the Niagara generators was closed several months later. The Folsom-Sacramento transmission, which I believe may be classed as the first polyphase high voltage system in America, was not undertaken until the following year.

In the Congress of 1904, the section which has to do with electric power transmission deals therefore with a branch of engineering which has had its commercial development within the past decade, and, furthermore, the great bulk of that which has commercial value and engineering interest does not date back more than half of that time.

Approximate statistics show that the apparatus manufactured by the leading American companies for power transmission at 10,000 volts or higher provides for the transmission of approximately 1,250,000 hp, all by polyphase current. These striking figures indicate a quantitative or commercial development, which is, however, no more remarkable than the qualitative or engineering development. The elementary diagram of a power transmission system with generator, raising transformers, transmission line and lowering transformers has been developed into great systems with many power-houses, with networks of high-tension circuits connecting many sub-stations, which in turn have distributing circuits with very exacting requirements. Substantially every element in the system from the generator shaft to the incandescent lamp, or motor pulley, has required the constant attention of the designer and engineer. Generator and transformer design, types of windings and of insulation, switchboard, switches, instruments, protective apparatus, insulators, pins and line construction have all passed through many stages of development since the early plants were installed. Each advance in voltage, each increase in power, each increase of distance, each station or sub-station added

to a system has increased former difficulties and has brought forth new ones.

Problems of transmission are not problems which can be solved in the laboratory alone. Apparatus must meet the precise conditions of operation and be judged by experience.

The transmission problem, moreover, is not one pertaining to a single plant. The conditions of climate and of service requirements are varied. That which is successful in one place, and for a given kind of service, may be wholly inadequate elsewhere.

The general engineering problems involved in high-tension transmission are not those for the individual, but, broadly speaking, they are for the engineering profession. We will not succeed by isolation but by cooperation. He who does not contribute to the general fund of experience and he who does not profit by the experience of others is narrow and short-sighted. Competition and rivalry should not limit and restrict progress, but should urge to better attainments. Research and experience, theory and practice must go hand in hand.

Well may we congratulate ourselves upon the progress, both quantitative and qualitative, which has been made in the past decade, but we have reached no limit, no resting place. There is every indication that the growing applications and the demands for power, the enlarging radius which high pressures make practicable will bring more difficult and more exacting problems to the engineer and will lead to results which in future may make our present record simply the small beginnings of what is to follow.

A great impetus was given to the polyphase system when it was adopted by the Niagara Falls Power Company and the selection of 25 cycles, a radical departure from the practice and the prevalent ideas of that time, was effective in making this frequency a recognized standard.

A few facts in connection with the power developments at Niagara Falls are significant and typical. From the first, a large portion, usually the greater part, of the power developed has been consumed by processes or industries which were not yet invented or perfected at the time that the Niagara development was undertaken. The initial installation of the Niagara Falls Power Company consisted of three generators with a combined output of 15,000 hp, although wheel pits were provided for two more units. The first power was delivered commercially in 1895, nine years

ago. Extensions have been rapid. This company has generators aggregating over 100,000 hp installed. Another company is developing 25,000 hp electrically, and plants are now under active construction for an additional output of nearly 500,000 hp.

Many of the electrical questions which are of particular interest at the present time are not broad and general, they are specific and in detail, they are with regard to the particular type, or form of apparatus, or method of construction. In recent conferences with the engineers of three transmission systems I found that each had a particular element in his system which was the source of most of his trouble, and yet, in two of the cases the elements most liable to give rise to trouble caused little or no apprehension in either of the other plants. The difficulties in one place may not be the difficulties in other places. Hence the value of free interchange of experience and of data.

A recent writer has said that the cost of a great exposition might well be borne by the general government as there would be value returned through the indirect impetus given to its citizens. Even from the inspiration given to a single individual there might come results which would justify the whole cost. We have come together for interchange of information and of ideas. Fortunate will we be if, supplementing the mutual helpfulness and assistance which is sure to follow, there may be also an outlining and consideration of the problems of the future. It is well to look to the details of our present apparatus and systems, we must be awake also to the discovery of things which are radically new in materials, in design, in method, which may better solve the problems we now have and which may enable us to enter into new fields.

DISCUSSION.

Chairman SCOTT: Let me speak a word on behalf of the officers of this Section. I think the first power transmission which can be considered broadly electric power transmission on a fairly long-distance and definite scale was the one at Telluride, Colorado, a 100-hp. motor operated over a few miles at 3,000 volts. It was my privilege to have much to do with the designing and arrangement of the apparatus and system for that operation, so that I think I take a just pride in having had something to do with the first American power-transmission system. Dr. Bell, our secretary, was at the World's Fair in Chicago on the occasion to which I referred; he was on his way to Redlands, Cal., to put in operation the Redlands plant, which transmitted three-phase currents at twenty-five or twenty-six hundred volts for a distance of eight miles, and was at the time the largest

power transmission. A little later, I think the next year, it was he, if I am correct, who started the Folsom-Sacramento plant which I have classed as the first real polyphase high-tension transmission plant. So that among your officers you have the pioneers in the business.

Dr. F. A. C. PERRINE: What was the date of the Standard Consolidated Plant of Bodie?

Chairman SCOTT: At Bodie, Cal., a plant, practically a duplicate of the Telluride plant, was put in operation in 1892 or the beginning of 1893.

Dr. BELL: A few words in reference to the early state of the art may possibly be of interest to some of the members. I remember very well the first start at polyphase alternating-current transmission. It was in 1892 when the two great rival companies were competing commercially, and both of them struggling with the possibilities of transmission. I remember coming that year to take charge of transmission work for the General Electric Co. and finding as a heritage a contract in Walla Walla, in the state of Washington, for a transmission of five miles, to the amount of about 150 horse-power. At that time, 1892, we were practically lacking in this country any means of doing that work. The heritage had come in the form of a contract for high-voltage direct-current machines and there was at that time in America no manufacturer who would tackle the proposition of making 150 horse-power direct-current machines to transmit power five miles at any kind of efficiency. The proposition as originally brought before me included a 2000-volt machine and there was not a maker in this country who dared wrestle with building a 2000-volt machine of that capacity. The contract had to be filled, and I remember almost the first thing I had to do in taking hold of that transmission work was to find some way of getting out of the difficulty, which was done by using a single-phase lighting machine, 150 kw, at each end, and starting the synchronous motor, which took all the power, by means of throwing the exciters of the two machines at extra high-voltage upon the line and so getting up speed. That plant may be running yet; it was running up to three or four years ago. By the next year, progress had been rapid and the three-phase generators were worked out so that that first Redlands plant was sold in February or March, 1893, and got installed just after the Electrical Congress, without any considerable difficulty. On that occasion, I believe, two three-phasers were commercially worked in parallel for the first time. The plant was sold under a guaranty, stimulated by the engineers of the company of which our honored president has long been the electrical light; a guaranty that required operating in parallel, and I think there was a doubt that lingered in the minds of a good many people as to whether it could be done. A time came when both generators were installed and the president of the company rode up through the canyon on a short hunting trip, and as he went through the station, and saw the preparations made for paralleling the machines, suggested that he would like to see that guaranty fulfilled then and there. I remember taking — not my life but my nerve in my hands, and parallelizing then and there the machines, and, for a wonder, they went together without the slightest difficulty. I say, for a wonder — I knew from experiments in the laboratory they must go together, and I knew perfectly well when they were

synchronized they would go together, but confidentially, I may be here justified in saying that the next two or three times we tried to parallel those machines there was trouble. That was the first of the American polyphase plants, if I possibly except a pair of little generators which were then running in Concord, N. H., aggregating 70 kw or 35 kw apiece. They were machines which had been remodeled from the old single-phasers and had surface-wound armatures, giving 500 volts or thereabouts, and the history of the installation of those two machines may be of interest. Another contract had been taken and was passed on to me at the same time, to-wit: in 1892,— a proposition for transmitting power five miles, in Concord, N. H., for the purpose of running small motors. That contract had been closed with the specification of using two 500-volt generators connected on a three-wire system. After much labor I succeeded in pursuading the agents and the buyers to the point of using three-phase apparatus. Some of the three-phase motors were delivered and it was necessary, prior to the installation of the large machines, which was waiting the completion of the dam, to do something toward supplying customers with motors. The company did not desire to put in any more 500-volt continuous-current motors, so two or three — three, I think, — polyphase induction motors — the first in commercial use in this country — were shipped up there and the two little generators were sent up after them and installed in a steam-driven station. Those, I believe, were actually the first polyphase machines which were in use in this country. Somewhat later, another interesting plant was installed, in Taftville, Conn. It was a duplicate of the Redlands plant, practically, on a five-mile transmission, which is not at all notable but at least interesting as being the first transmission for driving railway generators for street-car service. They were driven in connection with other mill machinery by a 250-hp. synchronous motor, the synchronous motor having auxiliary windings in the field and being started as an induction motor. In connection with that plant some of the early difficulties are forcibly brought to mind. There were no insulators at that time adequate for use as pull-off insulators in keeping up the line, and during one whole afternoon we ran the railway and the mills of 1,700 looms with arcs breaking every few minutes across the insulators at the end of the line, while an industrious assistant of mine, perched on an enormous pile of dirt which had been accumulated in the excavation of the tailrace, was making (to use a Hibernianism) snow-balls out of the dirt and throwing them at the insulators to break the arcs. Such were some of the asperities with which we had to contend in the very early days, but those days were, providentially, soon ended.

Mr. E. Kilburn Scott: There is an impression in Europe that the adoption of the polyphase alternating current at Niagara followed directly from the success of the Tivoli-Rome installation. I remember going down to see that particular plant soon after it was started, about 1892, and on signing the register, I remember seeing the names of the members of the Niagara commission. I really believe that the instant and complete success of that particular installation had great weight with them. We have

not much to show in England in transmission of power, in the early days, but perhaps I may be allowed to remind you of the pioneer work of Ferranti, when he transmitted power by alternating currents from Deptford to London, eleven miles at 10,000 volts. He proved that it was possible to transmit power at such a high pressure through underground insulated cables. That was a very important thing for us to know. We were not then allowed to run bare high-pressure wires. Our Board of Trade is much more reasonable now, I am glad to say.

Mr. Scott has mentioned that a large amount of transmission work has been done within the last five years, and especially on the Pacific coast. Is not this traceable to the peculiar geographical advantages there? The very high falls enable you to use the tangential water wheel, which is the most beautifully simple, as well as the cheapest, prime mover in the world. The steam-turbine cannot compare with it.

I am now engaged on a plant in North Wales, where we are using power from a lake on Mount Snowdon, and we have a fall there of 1150 feet; but I do not know of such another case in Great Britain. There are two or three others of 900 feet; but they require expensive hydraulic works to develop them. When I came to work out the details of the Snowdon plant, I was specially struck with the simplicity of a plant driven by high-pressure tangential water-wheels. With high falls, the water is generally pure and free from sand, as well as from organisms that cause growth in pipes. On low falls, the water is much more likely to contain organisms, and machines have had to be invented to scrape out the pipes. On the Pacific coast you have pure water, in some cases from glacial streams, and the reason why so much power transmission has centered there is largely due to those high falls.

Chairman SCOTT: The last speaker mentioned one of the geological conditions which has favored our transmissions in California, namely, the mountain ranges and the high falls. There is another which I think has been equally favorable to water-power development, and that is the lack of coal. The cost of fuel is high and water-power is resorted to as a necessity. I noticed when the pure water of California was mentioned as being the only thing to be found there, that our friend Mr. Hutton looked a little dubious. He appeared to be rather surprised at so general a statement.

Mr. R. S. HUTTON: Regarding the pureness of the water, Mr. Chairman, in the winter time, as in any other good country, we have rain. While our rainy season is rather short we have a fair share of it. A good many of our plants are located at points well down on the sides of the mountains, and above such points in earlier times the sides of the mountains have been considerably gouged out by the hydraulic mining processes. This has filled up a great many of the gulches, and left much debris, which the high water has gradually brought down, a little at a time, until we have in connection with our flumes found it necessary to install a very elaborate system of sand-catching basins, and methods of taking care of the conditions existing. Some of the original water-wheels installed, due to the earlier imperfect design and construction, gave considerable trouble in the matter of cutting of the buckets and parts with which the water

came in contact. This to-day has been considerably overcome, so that our wheels give us very little trouble from grit that may be in the water. The nozzles still get some of the effects of the cutting, but this is a small matter and is easily taken care of. Speaking about the high heads we have, just a few days before I left California, we put in operation a 5000-kw unit which, together with its water wheel, forms a very simple and compact design, simply a two-bearing unit, with water wheel overhanging. This unit operates at a speed of 400 revolutions per minute. The head of water used is 1,600 feet and sufficient power is derived from this to drive the generator at considerable over load with a six-inch nozzle. This, as I say, was just put in operation a few days before I left, and we of course do not know precisely what the result is going to be; but from former experience with other units, slightly smaller, we feel that we shall not have a large amount of trouble.

Mr. W. L. WATERS: As modern power transmission usually means three-phase transmission, I think Mr. Kilburn Scott made statements which were to the point when he called attention to the fact that the original polyphase work was done on the other side of the Atlantic. The first polyphase transmission on a commercial scale was the Lauffen transmission at the Frankfort Exposition in 1891, where, I think, 150 hp was transmitted 100 miles, at about 30,000 volts. The work done in the next few years was really single-phase work, and I think I am right in saying that both the Telluride and the Tivoli-Rome plants were single-phase. It was really three or four years later that the Niagara Falls transmission was started up, making the first large important polyphase transmission in this country. Certainly Mr. C. E. L. Brown deserves the credit of the pioneer work in polyphase transmission, and of showing that it was capable of commercial success.

Chairman SCOTT: I should have limited my comment here to work in America; I had that in mind, and in not discussing foreign work I did not mean to belittle it. I will add that limitation in the paper. If there is no further discussion we will adjourn until tomorrow morning.

TUESDAY MORNING SESSION, SEPTEMBER 13, 1905.

The Section was called to order by Chairman Scott at 9:30 a. m. The first paper was read, by Mr. J. S. Peck, on "The High-Tension Transformer in Long-Distance Power Transmission."

THE HIGH-TENSION TRANSFORMER IN LONG-DISTANCE POWER TRANSMISSION.

BY JOHN S. PECK.

The development of the high-tension transformer has been one of the great factors in the growth of long-distance power transmission which has occurred during the past decade. At the beginning of this period there were practically no transformers in commercial service of a capacity as great as 100 kw, or of a voltage exceeding 10,000. Today there are in America approximately 10,000 transformers of capacities ranging from 100 to 2,500 kw, wound for pressures of 10,000 to 60,000 volts. This development in high-voltage transformers is a direct result of a commercial demand for apparatus capable of transmitting larger and larger amounts of power over longer and longer distances.

At the beginning of this period of long-distance power development there was no past experience in high-voltage work upon which to base the designs of new lines of apparatus. Little was known of the characteristics of insulating materials and few materials which had proven satisfactory even for low voltages were available. Of the nature of the strains produced by lightning discharges, by switching, or by other static disturbances, nothing was known. Thus, the designer was forced to start upon the development of an entirely new class of apparatus, with no guide for his direction save his own good judgment. Under such conditions it is not to be wondered that mistakes were made, or that some trouble has been encountered with high-voltage apparatus, but rather that the number of such mistakes were so few and that the amount of trouble has been so small. The development of the transformer may be said to have progressed without interruption from the small and crude units of ten years ago to the large and highly perfected ones of today. One of the remarkable features of this development is the fact that on account of the rapidly increasing demand for units of larger size and higher voltage, it was not possible to wait for results which, under a more gradual development, would have been obtained from the actual operation of transformers

already manufactured; and so rapidly were designs and manufacturing methods changing that a transformer was often out of date before there was time for any inherent weakness to develop.

The state of the art of transformer manufacture has advanced to such a point that today the design of a 60,000-volt, 2,500 kw transformer is undertaken with a far greater assurance of success than was felt ten or twelve years ago in the design of a small 2,000-volt unit. An idea of this development may be obtained from the accompanying table, which is made up from the records of one of the largest electrical manufacturing companies. The transformers included in this list are all used for high-voltage transmission, and it is of interest to note that the 5,130 transformers represent an aggregate capacity of 1,059,838 kw—nearly 1,500,000 hp—the average size of unit being 210 kw.

Output of High-Voltage Transformers Made by Westinghouse Electric & Manufacturing Company from 1892 to 1903, inclusive.

Year.	No. of trans-formers.	Output kw.	Maximum voltage.	Maximum capacity kw.
1892	65	406	10,000	10
1893	19	272	3,000	19
1894	68	1,720	10,000	100
1895	78	4,215	10,000	200
1896	150	12,820	15,000	750
1897	165	21,091	30,000	850
1898	387	49,719	30,000	500
1899	662	119,492	33,000	1,875
1900	492	171,646	50,000	2,750
1901	997	201,475	50,000	1,000
1902	985	248,982	50,000	2,200
1903	971	228,000	60,000	2,500
Total	5,039	1,059,838	....	....

Transformers for long-distance transmission may be divided into two general classes: oil-insulated, and air-blast.

The oil-insulated transformers may be again divided into two general classes: self-cooling, and artificially cooled.

Practically all transformers are of the shell type of construction.

The working parts of the different classes of transformers are in

general similar, the principal difference being in the external case or housing. In all types the winding is made up of a number of thin flat coils, wound with a flat ribbon and with one turn per layer. These coils are assembled side by side and separated by insulating barriers and by spacing blocks, which permit a circulation of oil or air between them. The magnetic circuit is built up of laminations of specially selected and treated sheet steel. These laminations are securely held in place by end-frames surrounding the ends of the coils, and are held together by suitable bolts and braces. The case or housing is adapted for oil or air cooling as is required.

It has been found that in high-potential transformers there is, under certain conditions, an accumulation of the full line potential upon a few turns, so that for successful operation it becomes necessary to insulate the turns one from another in the most thorough and careful manner. The method of winding coils with one turn per layer affords an excellent means of accomplishing this result, as each turn can be insulated from every other one to any desired extent. A coil of this type has also comparatively few turns, so that a number of these coils are required for making up the total winding; thus the voltage on any one coil is reduced and the adjacent coils may be insulated from each other with insulating barriers of any desired thickness.

In order to keep down the reactance of the transformers, the primary and secondary coils are interlaced and, in general, the larger the transformer the more frequently are the coils interlaced.

In the construction of large transformers, the coils are very heavy, and in order that they may be thoroughly ventilated, it is necessary that their thickness be reduced to a minimum. Thus the problem of mechanically supporting them becomes a serious one, and in the design of such transformers the working out of the electrical design is a simple problem compared with that of designing proper methods for insulating and supporting the coils, so that they cannot become displaced or injured by electrical or mechanical forces. On certain large high-voltage transformers it is interesting to see the ingenious methods which have been worked out for mechanically supporting, for insulating and ventilating the windings.

The oil-insulated self-cooling transformer is wound for voltages as high as desired and for capacities as great as 500 kw. This transformer depends for its cooling upon radiation from the sur-

face of the case in which it is mounted. The only satisfactory case yet devised for a self-cooling transformer of large size is one made of heavy sheet iron, corrugated in such a manner as to give a very large exposed surface. The corrugated cases are mounted either in an angle-iron framework or with the sides set into a cast-iron base. A cast-iron top is usually provided and in this are placed suitable bushings for the primary and secondary leads. The self-cooling transformer has one great advantage over all other types, in that no extraneous devices are required for cooling, so that when once installed it will operate indefinitely with practically no attention.

The capacity of the self-cooling transformer is limited to approximately 500 kw. For greater capacities than this, the cost and dimensions of the case become excessive.

For many classes of service where no attention can be given to the apparatus, the self-cooling transformer is the only satisfactory type. This promises to be the case in single-phase railway work, where one or two transformers will be installed in out-of-way sub-stations, or perhaps in certain cases on poles where inspection can be made at rare intervals only.

The oil-insulated artificially cooled transformer may be wound for any voltage and for any desired capacity. Its construction differs from that of the oil-insulated self-cooled transformer principally in the form of case and in the cooling devices. A number of different methods have been proposed and tried for carrying off the heat, but one method is now almost always used. This consists in forcing or siphoning water through coils of brass or copper tubing placed inside the transformer case below the surface of the oil. This method of cooling is the most simple and direct of any of the artificial cooling systems.

The case for containing the oil is usually made of boiler-plates riveted and caulked. A cast-iron case and cover are provided and the terminals of the water cooling coils and the leads from the primary and secondary windings are carried through this cover.

Another system of cooling, used to a limited extent, consists in drawing the hot oil away from the transformer tanks, circulating it through a cooling coil which is immersed in running water, and then returning the cooled oil to the transformer case. The circulation is maintained by means of a small motor-driven pump. The advantage of this system over the first one mentioned is that in case of a leak in the cooling system the oil will escape into the water

instead of the water into the oil; but as there are very few cases on record where trouble has resulted from leaky water-coils, this advantage does not seem to be of great moment. To offset this single advantage, a pump, a motor, a cooling tank and a system of oil piping are required for the cooling system, and there is the possibility that should a deposit form in the oil it will gather on the inside of the tubes and prevent the circulation and cooling of the oil.

The air-blast transformer, as its name implies, is one in which the cooling is accomplished by means of a forced draught of air. It may be wound for pressures not exceeding approximately 33,000 volts, in units of any desired capacity.

The transformer proper is mounted in a cast-iron housing, so arranged that air, which is admitted at the base, may pass through the cooling ducts between the coils and through those in the iron. Two separate air-passages are provided, one for cooling the coils and the other for cooling the iron. Dampers are arranged for controlling the air in either passage. The transformers are usually placed above an air-chamber in which a pressure usually less than one ounce per square inch, above the surrounding air, is maintained. The air is supplied from large steel-plate fans, which are usually directly connected to induction motors. The power required for cooling is small, being usually one-tenth to one-fourth of one per cent of the transformer capacity.

On account of the difficulty of eliminating static discharges over the surfaces of the coils of the air-blast transformer, it has been found impractical to use this type of construction for pressures exceeding approximately 33,000 volts, and the greatest success has been obtained at voltages not exceeding 20,000.

During the past year, a considerable amount of discussion has occurred regarding the relative fire risks of oil-insulated and air-blast transformers. The general results brought out seem to indicate that so far as actual damage to the transformer itself is concerned, either by internal or external heat, the risk is much greater with the air-blast transformer than with the oil-insulated type. This greater risk of the air-blast transformer results, not only from the more inflammable nature of its insulation, but also on account of the presence of the air blast, which tends to increase the rate of combustion, as well as by the open construction necessitated by the method of cooling.

In the oil-insulated transformer, the oil cannot be ignited unless

it is first raised to a very high temperature. Oil also acts as an extinguisher of arcs which occur below its surface, and, if the transformer is inclosed in a tight case, the oil, even if ignited, cannot continue to burn, on account of lack of fresh air.

There is, however, a danger incident to the operation of the oil-insulated transformer which is due to the fact that oil-vapor, when mixed with the proper proportion of air, forms an explosive mixture, which, becoming ignited, may burst the containing case and permit the oil to escape. With large transformers it is now customary to use a practically air-tight case, sufficiently strong to withstand an internal pressure of approximately 100 pounds per square inch, which is probably in excess of any pressure that can actually be obtained. In large transformer installations, each transformer, or each group of transformers, is often placed in a vault or pit, which is properly drained and, in event of a case being damaged by external causes so that oil escapes, it will not spread about the station floor, but be carried away by the drain.

With every precaution taken, the presence of large quantities of oil must constitute a certain fire risk, and for this reason it has become the general practice to specify air-blast transformers for use in sub-stations which are located in thickly populated portions of large cities. Such transformers are usually wound for 6,000 to 15,000 volts, for which pressures the air blast transformer is well adapted. For very high voltages, it is of course necessary to use oil-insulated transformers, taking such precautions in their installation, as to reduce to a minimum the danger to surrounding buildings or apparatus.

A method for reducing the fire hazard of the oil-insulated transformer which has been used to a limited extent, consists in placing the transformer in a tight case with a vent-pipe connected to the top of the dome-shaped cover. At the bottom of the case a connection is made with the water-mains, so that, in case of necessity, water can be admitted at the bottom of the case, driving out the oil through the top vent and leaving the case filled with water. The vent may be connected with a sewer, or with a suitable tank for receiving the oil.

A mineral oil is used in transformers. It should have a fire-test of not less than 200 deg. C.; its evaporation at normal running temperatures should be negligible; it should be free from acids, alkalis, water or sulphur compounds, and should show no deposit at the maximum operating temperature of the transformer.

In Europe, the three-phase transformer has been very extensively used. In America it has not come into general use. This is doubtless due to the fact that single-phase transformers present a much more flexible arrangement than one three-phase unit, while there is but a slight difference in cost in favor of the three-phase unit.

For transmission voltages not exceeding 33,000 volts, it is customary to connect both high-tension and low-tension windings of transformers in delta, as with this arrangement two transformers will continue to deliver three-phase currents even though one transformer be disabled. For higher voltages, transformers are frequently connected with low-tension windings in delta and high-tension windings in star. This permits the grounding of the neutral point of the system, limiting the voltage between any wire and ground to 58 per cent of the line voltage. The winding and insulating of the transformer is also somewhat facilitated, on account

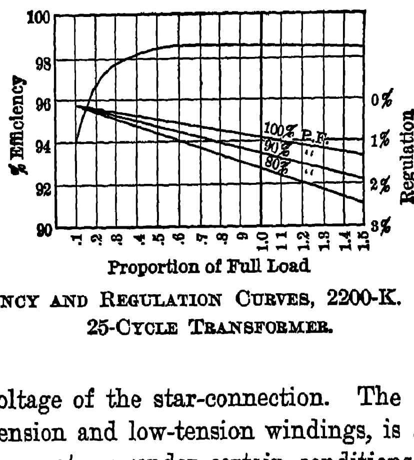


FIG. 1. EFFICIENCY AND REGULATION CURVES, 2200-K. W., 50,000 VOLT, 25-CYCLE TRANSFORMER.

of the lower voltage of the star-connection. The star-connection, on both high-tension and low-tension windings, is apt to prove an unstable arrangement, as, under certain conditions, it permits the full line voltage to be concentrated upon two of the transformers. In general this connection should not be used.

The efficiency and regulation obtained on transformers is probably superior to that of any other apparatus in the transmission system. On large units, even though wound for low frequency and high voltage, efficiencies of 98.5 per cent may be obtained. Fig. 1 shows an efficiency curve of a 2220 kw transformer, for a frequency of 30 cycles, 50,000 to 1100 volts. It should be noted that the efficiency is practically constant at 98.5 per cent from three-quar-

ters to one and one-half load. The remarkably close regulation of this transformer even with loads of low power-factor should be noted also.

From the records of one of the large manufacturing companies, certain data has been obtained regarding the capacities, voltages, and output of high-voltage transformers during the past ten or twelve years. These results have been prepared in graphic form, and appear in Figs. 2, 3 and 4. These curves give a fair idea of the progress in the state of the art of high-voltage transformer

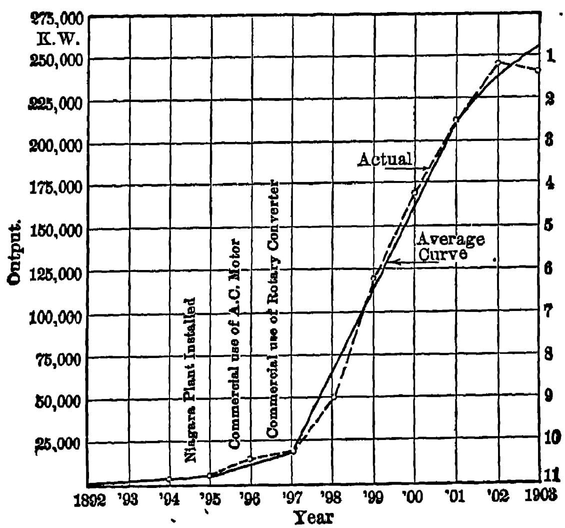


FIG. 2. OUTPUT OF HIGH-VOLTAGE TRANSFORMERS, 1892 TO 1904.

building. Fig. 2 shows the output of high-voltage transformers for different years. It seems almost incredible that in ten years' time the output per year should have increased from 300 or 400 kw to 250,000 kw. Upon this curve the effect of the installation of the Niagara plant, as well as the introduction of the alternating-current motor and the converter, may be clearly seen. The effect of the recent financial depression is also shown in a decreased output for 1903 over that of 1902.

Fig. 3 shows the maximum size of unit manufactured during the different years, also the average size of unit for the different years. In eight years time, the maximum unit increased from 10 kw to 2750 kw—275 times—while the increase in the average

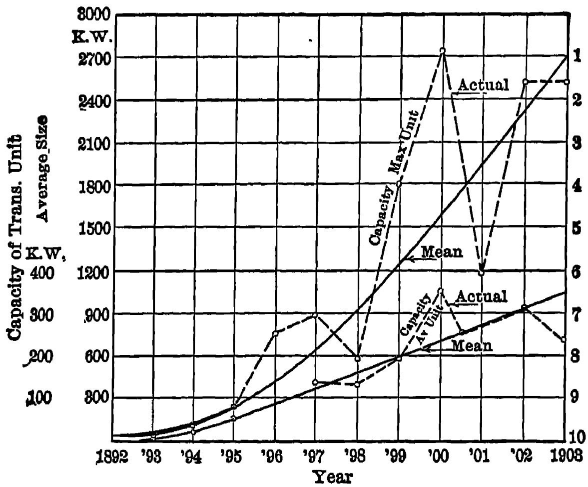


FIG. 3. MAXIMUM AND AVERAGE CAPACITY OF TRANSFORMER UNITS FOR DIFFERENT YEARS.

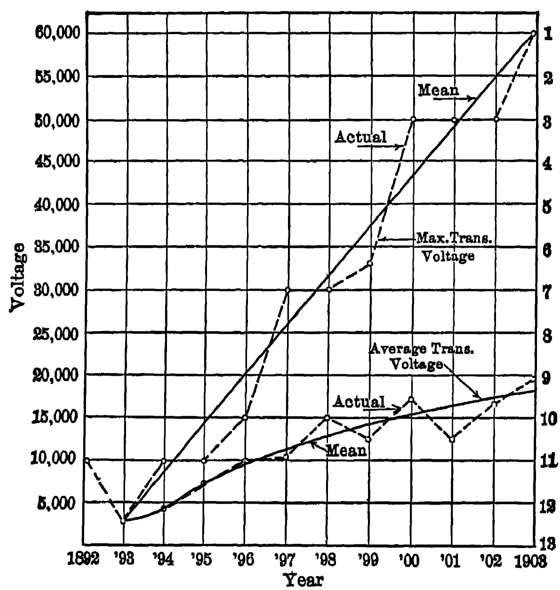


FIG. 4. MAXIMUM AND AVERAGE TRANSFORMER VOLTAGES, 1892 TO 1904.

size of unit has been from 10 kw to 250 kw—an increase of 25 times.

Fig. 4 shows the maximum voltage for which a commercial transformer was wound during the different years, also the average voltage during the different years. It will be noted that the increase has been from 10,000 to 60,000 volts, not nearly so great an increase as that in size, but one which represents far greater difficulties to the transformer manufacturer. The average pressure seems to be growing constant at approximately 15,000 volts. This is due doubtless to the fact that a very large number of the transformers sold are for use in large cities on 10,000-volt service for supplying converters for railway or lighting service.

Discussion.

Chairman Scott: The one thing which has given prominence to the alternating current and which has made possible the present types of power transmission and the use of high voltages is the transformer — a piece of apparatus most simple in itself. The component parts are most elementary in kind and for demonstration purposes very simple elements will suffice. But the transformer for use has undergone a very great development and many of the points to which Mr. Peck has referred are the points of engineering development of the transformer. In a certain way the lines of development have not departed from the earliest types. The type of transformer used in the first 10,000-volt transmission in this country, is, in its essential particulars, the same as the transformer used to-day. The details, the form of iron plate, the shape of coils, and the number of coils has changed in the development of the larger transformer. The oil insulation is the same. What we have done is to develop one type. It will be valuable in the discussion of this subject to have any comments upon the immediate points taken up in the paper and the particular usefulness of the various types. It would also be serviceable to have any suggestions on departures from this type. Are we in future to keep along the same line? Will the transformers of ten years hence be essentially those of to-day or will they be along radically different lines? The paper is open for discussion.

Mr. Francis O. Blackwell: I cannot agree with Mr. Peck regarding there being practically no fire risk with oil transformers. In large stations the transformer cases contain hundreds of barrels of oil. It is true that, in most cases of power-houses being destroyed by fire, the evidence indicates that the fire originated in combustible material in the neighborhood of the transformer and not in the transformer itself. The oil leakage from the transformer, which cannot be entirely prevented, is a source of danger. If a fire starts near the transformer and heats it up sufficiently, it will turn it into a gas producer and sufficient gas can be turned out to melt up all the iron work and machinery in any power-house. I think

that, when you install such a large body of oil in a building, you would at least take the same precautions against fire that you would had you one or two barrels of illuminating or lubricating oil in a factory. The insurance rules would require you to place such oil in a separate fireproof room. In power-houses and sub-stations, which I have recently designed, each transformer is enclosed in an airtight fireproof compartment. These compartments prevent the accumulation of combustible material in the neighborhood of the transformer, and, further, should a fire start, it will smother itself out as soon as the oxygen in the room is consumed.

There is another matter in connection with Mr. Peck's paper to which I would like to call attention and that is — the relation of efficiency to cost. A transformer designed for, say, 98 per cent efficiency, will cost nearly twice as much as one with 96 per cent efficiency. Expressed in another way — if you cut your losses in two you must use twice as much material in the construction of the transformer. It is an open question, therefore, as to how high in efficiency it is economical to go. The interest on the cost of the transformer might readily be more than the value of the power saved.

Mr. E. Kilburn Scott: We, in England, were using oil at a very early date; but our experience was unfortunate and its use was dropped altogether. We were surprised to hear some time afterward that oil was proving a success in America. Any oil which we now use for the purpose is obtained from the States, and if the author of the paper would say something about the way in which this oil is prepared, it would be appreciated. American makers treat it in some way that our manufacturers apparently do not know about; at any rate, we cannot get suitable oil in England.

Regarding the cooling by air, it has occurred to me that probably air under considerable pressure might be used for the transformer which will have to be installed for working main-line railways by alternating currents. I do not know whether you have noticed how when coalcutting machines are worked with compressed air, snow forms on the pipes and valves, owing to the sudden expansion of the air when it leaves the exhaust. This is a common occurrence in machinery driven by compressed air. Now I think that probably the transformers on railways could be cooled by having compressing stations at various points, to effect the cooling by this sudden expansion of air.

Coming to the question of the containing case, I notice many transformer cases are carefully ribbed outside, but are left smooth inside. This is probably done for ease in making the casting; but I think it would pay to incur a little more expense, and rib the inside of the cases as well. In fact, I think corrugated iron sheeting closed up (that is to say the pitch of the corrugations reduced from the usual three inches to say one inch) would be very effective, as it would give a large inside cooling surface, as well as a large outside cooling surface. We do not want great thick castings. To make a casting, say, six feet high, the bottom will have to be 1½ inches thick; because the moulder cannot very well get it thinner. The sides will, therefore, vary from 1½ inches to ½ inch, or so, at the top

and this is very thick metal through which to expect the heat to travel. I think the walls should be made of thin corrugated steel, as it would not only give ample cooling surface, but also great strength.

Speaking of the air-blast for cooling, it may be of interest to mention that the first Thomson electric welding plant shown at the Glasgow Exhibition about 1888, was bought by Clarke, Chapman & Co., and employed by them for welding connecting rods, etc., for ship's winches. They tried to use it for larger work and had several burn outs. On their asking my advice, I suggested turning the blast from the Smith's hearths through the electrical apparatus and this was done. It was probably one of the first examples of air-blast cooling of electrical apparatus.

Dr. Louis Bell: With respect to these large oil-cooled transformers, I think we all appreciate the danger to which Mr. Blackwell has alluded — that is, the fire danger; but perhaps we do not all appreciate at once the troubles which complete isolation of transformers invites. For example, you can undoubtedly box up a transformer or any other piece of apparatus so that a fire originating in it or communicating to it cannot possibly find its way out of the space in which it is placed, but in doing that you necessarily sacrifice a good deal of simplicity. I think the tendency in modern practice, the practice of the next few years, is going to be greatly in the direction of simplification of stations, simplification of all the connections possible, and the abolition of a great deal of accessory equipment and apparatus which now forms a very formidable feature of the cost and maintenance of many large stations. To that end I think that the direction in which our energies should be spent is toward keeping fire away from transformers rather than making too elaborate provisions for confining it to them after it gets in. It is better to lock the door before the horse is stolen. And it seems to me that a proper oil transformer runs very little risk, according to my experience, of getting on fire from the inside. As Mr. Blackwell very justly remarked, the danger is on the outside. And if you keep combustible materials away from your transformers, just as you would keep it away from any other place, the whole plant is much simplified. The danger at stations, according to the observation of a good many of us, I think, is in about the last place where one would at first suppose, that is to say, in the floor. You can design a fire-proof wall, you can design a fire-proof roof — fire-proof in any ordinary sense of the term, but to get an adequate floor on a station is a more serious problem. Concrete floors, you know, if well soaked from leakage of lubricants or anything of that kind, will furnish a very respectable furnace. I know one large factory in the East that was totally destroyed; the interior of it became a furnace on account of a floor which was supposed to be fire-proof but was charged with oil. I think if you pay attention to the station and keep combustibles away as far as possible from the outside of the transformers and their connections, including cables, that the danger of fire will be very much reduced. As it is now, I have, time and again, been in stations with first-class dynamo equipment, with the best modern transformers, and with some foolish collection of accessories arranged so as to catch any flames that might come

therefrom. This is particularly true of the switchboard as found in many power-transmission stations. Time and again I have seen a switchboard which was simply a fire trap, with a great mass of insulated wires and other stuff which will burn at high temperatures, snugly tucked away behind it, in the interest of compactness, with the result that if anything went wrong on that board you would have a little furnace started, capable of heating things even to the point of ignition of oil in the vicinity. I think that in the safety of transformers and other apparatus, the floor at the station is a matter that is too often neglected. As regards air-blast transformers, they are not faultless as a fire risk. I have seen a transformer, which was supposed to have gone out, burn on all night, scattering around cinders liberally. It seems to me that our work should be largely in the line of the prevention of the communication of any fire to the station or the spreading of any fire which may originate from a short-circuit. If you do not crowd the place too much; if you do not attempt to build a station too compact — and most power-transmission stations are in places where compactness is not necessary — you can avoid a great many of these dangers. It is very pretty to go into a station and say "Here is our beautiful, compact switchboard; here are our accessories of various kinds; you see there isn't an inch of waste space." Well, waste space is sometimes the very best insurance that we can have, particularly in fire risks.

Dr. F. A. C. PERRINE: I think we should not allow to pass, without correction, an apparent error in observation that Mr. Kilburn Scott has made on his American tour in regard to the self-cooled transformers, as we call them. There are four types in this country: We have the boiler-iron case, smooth inside and out; we have a corrugated sheet-iron case which is corrugated inside and out; we have a corrugated cast-iron case which is corrugated inside and out; and the fourth, which is the only one which corresponds to his description, is a boiler-iron case with external or iron radiating strips. So far as I know, there are not made in this country any cases of cast-iron with external radiating strips and smooth internal surface. A majority of the large self-cooled transformers made in this country are made either with corrugated sheet-iron cases, corrugated inside and out, or corrugated cast-iron cases, corrugated inside and out. So that the suggestion that he makes of radiating strips passing within the oil, as well as outside into the air, is actually our practice.

Mr. J. S. PECK: At one time the Westinghouse Company made a case which was smooth inside. First we had it ribbed inside and outside, then we found that the ribs inside did no good so we cut them off and left the ribs outside. Now I think the explanation of this was, that for heat to get from the oil into the cast iron is a comparatively simple matter. The whole trouble comes in getting the heat from the cast iron into the surrounding air, and I don't think — in fact I am very sure — that it would not do any good to put ribs inside.

Dr. PERRINE: Are any such transformers being manufactured now?

Mr. PECK: As far as I know there are none.

Mr. W. L. WATERS: I think Mr. Blackwell called attention to an important fact when he pointed out that the cost of a transformer depends

upon its efficiency. Apart from this question of efficiency, the rating of a transformer is simply a question of getting rid of the heat developed without damaging the insulation. And therein lies the advantage of a water-cooled transformer, as in this type you can carry away a considerably larger amount of heat by increasing your circulation of water. So that you can make a much cheaper transformer if you sacrifice efficiency, and increase the circulation of your water in this type of transformer.

In regard to the point that Mr. Kilburn Scott brought up about the quality of oil, I think that the only way you can rely on that is to purify, or bring the oil up to standard, yourself. We had considerable trouble lately with a large shipment of transformers which was held up on account of the quality of the oil received from the Vacuum Oil Company. Apparently the oil may be all right when it leaves the refinery, but it may not be all right by the time it is put into the transformer. The only thing you can do, is to dry the oil and filter it yourself, and repeat the process until it stands a definite sparking test.

Mr. E. KILBURN SCOTT: Do you use resin oil?

Mr. WATERS: No; it is ordinary mineral oil, petroleum oil.

Mr. E. KILBURN SCOTT: The stuff we use is resin.

Mr. WATERS: I never heard of resin oil being used. I think Mr. Peck is perfectly correct in what he says about the ribs on the inside of a transformer casing. If you take the temperature of the oil and the temperature of the case and the air you will see that the drop of temperature is almost entirely at the surface of the iron and air, and there is only a very small drop, may be 5 degrees, between the oil and the case, so that whether you have internal ribs or not doesn't really make much difference. And it is well recognized that when a body is cooling in contact with a fluid, the drop of heat potential across the surface, that is, the heat contact resistance, is much less in the case where this fluid is a liquid than in the case where it is a gas. It would only be a waste of space and material to put ribs on the inside, as well as on the outside, of a transformer casing.

Prof. F. G. BAUM: I would like to make a short statement to answer numerous questions that have come to us on our system regarding the fire at Colgate two years ago, and also to answer Mr. Blackwell in regard to a question of the relative fire risk of the two types of transformers. In Colgate we had the transformers in the power-house, setting under a gallery constructed mainly of wood, the main frame being of iron, the smaller working being of wood. The fire started owing to an imperfect, badly designed, oil-switch and not, as generally given out, due to any trouble in the transformer. The fire raged fiercely, so fiercely that it bent the iron in the roofs, bent the eye-beams on the gallery, warped the iron out of shape, yet did not injure a single transformer except that in one transformer two of the layers of the wraps had be to be removed and re-taped. The oil in only one transformer caught fire; the oil burned down in it about half way and stopped. The fire raged through a length of 150 feet. There were something like 25 transformers in the building, each of which had about four barrels of oil. And I think that experience demonstrates the extent of the fire risk of oil-type transformers.

Mr. F. O. BLACKWELL: In regard to the insulating value of trans-

former oil as effected by moisture, we recently had an experience with a number of large transformers wound for 60,000 volts. When these were set up at the works of the manufacturer they stood all tests successfully, but after they had been installed and put in actual service it was found that the high potential current arced through the oil to the low potential coil and to ground. Moisture in the oil could not be detected by chemical analysis, but by placing a small quantity in a bottle filled with chloride of lime it was found that the insulating resistance could be raised to its proper value. All of the oil was finally treated by forcing hot air through it, until the whole body of the oil was raised above the flashing point which dried it out and brought it back to its original dielectric strength. An investigation as to why the oil had deteriorated so much developed the fact that the barrels in which it was shipped had not been thoroughly dried and cleaned before they were filled.

Chairman SCOTT: If there is no further general discussion we will ask Mr. Peck to close the discussion, because time is becoming short.

Mr. PECK: I agree in general with what Mr. Blackwell said about the risk of oil-insulated transformers. The risk comes not from internal damage to the transformer itself but damages which may be done to external apparatus by the escape of the oil, and if it can be put into tight cases or tight vaults or, as is being done in some cases, put in tight cases and then put in vaults, not tight, but built up perhaps half the height of the transformer — pits, in other words,— and these are thorough drained, I think any of those precautions will go a long way to eliminate the fire risk. As to the oil, a mineral oil is used and it is bought under very strict specifications; it must be free from acids, alkalis, or sulphur compounds, and free from water. Great care must be taken to prevent oil from absorbing moisture or other impurities during the time of transit — from the time that it leaves the manufacturer until it is placed in the transformer cases. As to the thickness of castings, of course it is an advantage as far as the dissipation of heat is concerned to have the castings or have the metal as thin as possible, although I do not think that the drop in heat potential through the metal is ordinarily of great importance. Those castings are usually made as thin as they can be made and cast. That is the determining factor.

Mr. E. KILBURN SCOTT: Do you think that the oil in transit could absorb moisture if it happened to get in a damp situation, after being thoroughly dried out?

Mr. PECK: I think there is no doubt that it would.

CHAIRMAN SCOTT: The papers in the various sections were written in response to invitations sent out by officers of the Congress. The papers which have come in response have sometimes been more appropriate to other sections than to the one for which they were invited. For that reason a few papers have been taken from this section and a few papers have been brought from other sections here. One of the latter is "Notes on Experiments With Transformers for Very High Voltages," by Prof. Harold B. Smith, who is present, and will now kindly read the paper.

NOTES ON EXPERIMENTS WITH TRANSFORMERS FOR VERY HIGH POTENTIALS.

BY PROF. HAROLD B. SMITH, *Worcester Polytechnic Institute.*

The attention of the writer was first directed toward the problems involved in the production and application of high potentials of low frequency by certain of the exhibits at the Chicago Exposition of 1893, and particularly by the discussion before the International Electrical Congress of 1893 on power transmission.[1]

As a result of this interest, during the college year 1893–94, in connection with the direction of the School of Electrical Engineering at Purdue University, two senior students[2] at the University designed and constructed, under the writer's supervision, a small transformer to give an effective secondary potential of 10,000 volts. This transformer was constructed with but slight knowledge of the difficulties involved and was a failure except for the many valuable lessons received from successive attempts to operate it under the proposed conditions.[3] The following year this transformer was reconstructed by two senior students at the University[4] and was operated for some time before a final break-down occurred, but there could be no hope for the final success of such a transformer.

Following a suggestion by Tesla in a paper before the Institution of Electrical Engineers,[5] paraffin oil was heated, and by means of an air-pump drawn into a closed metal-lined box containing the core and windings. The oil apparently penetrated to all the surfaces of the core and windings, and it is probable that, so far as this part of the work is concerned, good results were secured; but un-

1. *Proceedings* of the International Electrical Congress, 1893, pp. 422–472.
2. G. G. Phillips and S. Moore, Thesis, "The Design and Construction of a High Voltage Transformer." Purdue University, 1894.
3. Primary, 1000 volts; secondary 10,000 volts; frequency 140. Primary had 248 turns, No. 14 B & S, and secondary 2840 turns No. 22 B & S. Core made of No. 16 iron wire.
4. Messrs. A. C. Bunker and C. C. Chappelle.
5. *Journal* of the Institution of Electrical Engineers, Vol. 21, p. 79.

fortunately rubber insulation was used on the secondary winding and this was promptly softened by the oil.

While this transformer was a failure in all respects, except that it led to success with later transformers, no responsibility for this failure should rest upon the four young men who assisted in its design and construction, as the writer was responsible for the important features of the design and the failure should be assumed by him alone.

On account of the pressure of many duties and the interruption of this work occasioned by the acceptance of the chair of Electrical Engineering at the Worcester Polytechnic Institute in 1896, this work was not continued until the college year 1897–98, when two graduate students[6] in electrical engineering at the Institute, under the writer's direction, undertook the design and construction of a 150,000-volt transformer, which was completed early in the spring of 1898. The experiences with the transformer of 1894, the succeeding interval of four years for occasional study of the various causes of its failure, together with many valuable suggestions from Prof. J. O. Phelon of the Worcester Polytechnic Institute and the remarkably able manner in which the two men who were engaged upon this work carried out the details of the design and construction, account for the thorough success of this second transformer.

A reference to this transformer, which had a ratio of voltages of 1 to 1500, and an illustration showing its construction appear in the *Transactions* of the American Institute of Electrical Engineers[7] in a note communicated by the writer to the discussion of the paper by Steinmetz on the "Dielectric Strength of Air.[8] More detailed descriptions of this transformer appear elsewhere[9] so that no extended description need be given here. However, a statement of experience with this transformer for the past six years may have some interest and value.

For several years the transformer was in fairly constant experimental service in the laboratories of the Institute on work[10] which

6. Ellery B. Paine and Harry E. Gough, Thesis, "High-Potential Discharges in Dielectrics." Worcester Polytechnic Institute, 1898.

7. *Transactions* American Institute of Electrical Engineers, Vol. 15, p. 328.

8. *Ibid*, p. 281.

9. *Journal* of the Worcester Polytechnic Institute, Vol. 1, p. 356; *Electrical World*, Vol. 32, p. 63.

10. S. S. Edmands and W. E. Foster, Thesis, "Distribution of Potentials Between High-Potential Conductors." C. E. Eveleth and E. F. Gould, Thesis, "Dielectric Strength of Oils." O. P. Tyler and S. T. Willis,

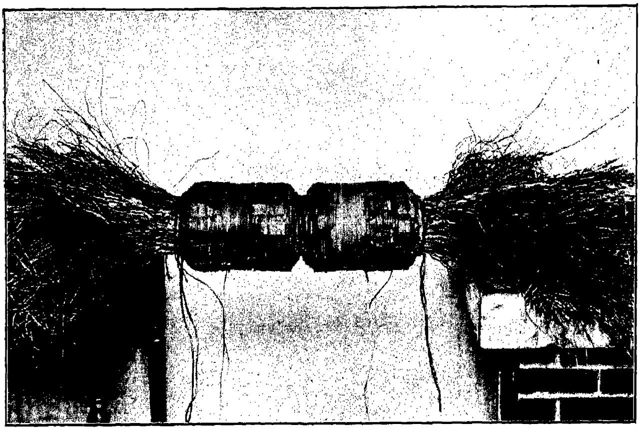


FIG. 1.— 10,000-VOLT TRANSFORMER, 1893.

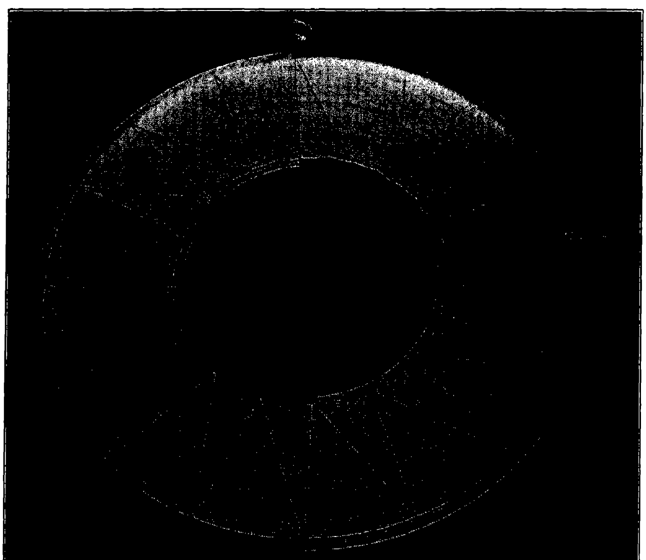


FIG. 8.— COIL OF 200,000-VOLT TRANSFORMER, 1904.

involved operation at potentials as high as 190,000 effective volts and for many days was operated for 10 hours per day at 175,000 effective volts. Nearly a year ago, this transformer was sold to be used for commercial testing by a company manufacturing insulators and information has been received recently of its continued satisfactory daily service at potentials ranging up to its rated capacity.

This transformer was exhibited at the Saratoga (1903) Convention of the American Street Railway Association, and at this time several coils of the secondary winding were injured in shipment and had to be replaced; with this exception, practically no difficulty has ever been experienced in its operation. It was designed primarily for experimental work in the laboratories of the Worcester Polytechnic Institute and many details of construction would naturally be changed in a design intended for commercial service, although the general features of the design have demonstrated their reliability for this class of work.

In the fall of 1899, two seniors[11] in electrical engineering at the Institute undertook the development of a transformer for still higher potentials and in the spring of 1900 produced, under the direction of the writer, a transformer designed for a secondary potential of 330,000 volts at 60 cycles per second; but under test, this transformer failed to develop potentials higher than 210,000 effective volts at the terminals of the secondary circuit.

Failure to operate this transformer at higher potentials may be attributed, in part, to an absence of knowledge at the time of its design, of phenomena which occur at the higher potentials and which had not been observed in the operation of the 1898 transformer below 175,000 volts. In part, the failure of this transformer may also be attributed to defects introduced by frail construction and faulty design of the windings, as the transformer was regarded as a purely experimental affair, and expensive construction

Thesis, "High-Potential Tests of Solid Dielectrics." E. H. Ginn and W. J. Quinn, Thesis, "Surface Leakage on High-Potential Insulators." J. M. Bryant, Thesis, "The Commercial Production of Ozone." A. L. Cook, A. P. Davis and J. B. Wiard, Thesis, "Leakage Losses on High-Potential Transmission Lines." W. M. Adams and W. H. Sigourney, Thesis, "Surface Leakage on High-Potential Insulating Materials." H. W. Morehouse and E. L. Stone, Thesis, "The Distribution of Potentials Between High-Potential Conductors."

11. H. I. Cross and S. E. Whalley, Thesis, "The Design, Construction and Test of a High-Potential Transformer." Worcester Polytechnic Institute, 1900.

was avoided whenever possible and in too great a measure for satisfactory results. However, as in the case of the 1894 transformer, failure to accomplish the results anticipated led to a closer study of the phenomena involved in this class of work, and to success later in the production of a transformer for even higher potentials.

During the college year 1900–01, four graduate students[12] in electrical engineering at the Institute undertook the design and construction of a 500,000-volt transformer at the suggestion and under the direction of the writer. This transformer was in operation early in May, 1901, and at that time developed a secondary potential, at 60 cycles per second, which was capable of disrupting a 48-in. (1.22 meter) air-gap between sharp needle points.

As this is undoubtedly the first transformer and, so far as the writer is informed, the only transformer which, up to the present time, has, with a *single transformation* or even with several transformations by a number of transformers, secured low-frequency potentials in the neighborhood of one-half million effective or three-quarters of a million maximum volts, a brief description may be of value.

The design of this transformer called for a ratio of transformation of 1 to 2520, at 60 cycles, and a maximum core density of 8600 gausses, when at a secondary potential of 500,000 effective volts. The primary winding consisted of 46 turns of heavy stranded conductor — 23 turns on each core — in series for a primary potential of 200 volts, 60 cycles, giving a maximum magnetic flux of about 1,600,000 maxwells at full rated voltage. The secondary winding was subdivided into 66 coils, each of which was further subdivided by cotton tape into four sections. There was a total of 115,920 turns of number 32 B & S double cotton-covered wire in the secondary winding. Each coil was wound in a spool turned from thoroughly seasoned white pine of the very best quality and carefully selected stock. The cross-section of the spool is shown in Fig. 5, and the outside diameters of the spools ranged regularly from 16 ins. up to 32 ins.

The middle of the secondary winding was connected to the core and to the primary winding, and carefully earthed in most of the work which has been done with this transformer, although it has

12. R. S. Beers, F. R. Davis, E. H. Ginn, W. J. Quinn, Thesis, "The Design, Construction and Test of a 500,000-Volt Transformer." Worcester Polytechnic Institute, 1901.

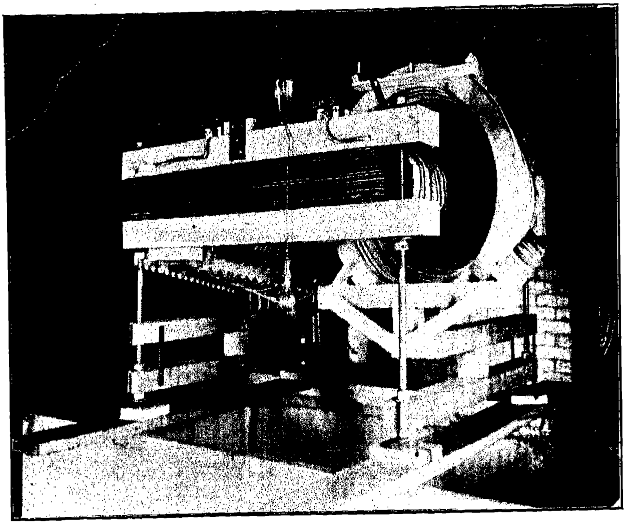


Fig. 4.—500,000-volt transformer, 1901.

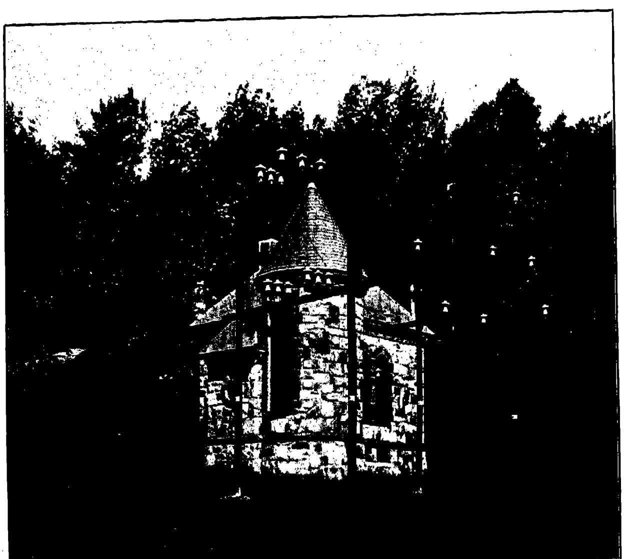


Fig. 6.—High-potential laboratory, Worcester Polytechnic Institute.

been operated on a number of occasions without earthing the secondary circuit. The primary circuit, supplied with current from a generator which may be regulated as desired, was always earthed for the protection of the operator.

This transformer has been used for three years upon work of investigation connected with various thesis subjects[13] upon which students at the Institute have been engaged, together with some work carried out personally by the writer upon the dielectric properties of air and oils. During this time, it has been found necessary upon two or three occasions to cut out a few faulty coils of the secondary winding; but when it is stated that this winding contains about 125 miles (about 200 km) of No. 32 B & S wire which was not wound in layers, although each coil may develop from 8000 to 9000 volts, this is not surprising. Tests made with this transformer indicate that, with the substitution of a modification of the secondary winding which has been introduced by the writer in transformers of more recent design, a potential of not less than 750,000 volts effective, or over a million volts maximum, can be secured from this transformer. As soon as suitable opportunity presents itself, it is proposed to make this change. The transformer is located in a separate transformer-house on the campus of the Institute, at some distance from other buildings on account of the fire risk occasioned by over a thousand gallons (3800 litres) of oil required for insulating the secondary winding.

On May 27 of this year, an order was placed with the writer for a 200-kw, 300,000-volt transformer which was shipped to its destination July 18, and has recently been placed in operation and accepted by the purchaser.[14] As this transformer was designed along lines which will permit its operation at considerably more than its rated voltage and power output and probably constitutes the largest transformer yet built for very high potentials, the writer has been permitted to give the following brief description:

Fig. 6 shows an assembled view of the transformer core and secondary winding ready to be immersed in the oil contained in the transformer tank. The connections to the primary and secondary

13. R. S. Beers, F. R. Davis, E. H. Ginn, W. J. Quinn, Thesis, "Investigation of the Dielectric Strength of Air and Oils." L. Day and C. F. Harding, Thesis, "Investigation of the Leakage Loss Between High-Potential Transmission Conductors." A. L. Cook, A. P. Davis, G. E. Munroe, E. W. Kimball, J. A. Sandford, Thesis, "Investigation of the Leakage Loss Between High-Potential Conductors."

14. The Locke Insulator Mfg. Co., Victor, N. Y.

circuits are so arranged as to permit full rated power output at secondary potentials of either 75,000, 150,000 or 300,000 volts, 60 cycles. The maximum ratio of primary and secondary turns is 316, as the primary is designed to be supplied from a 1040-volt generator. The secondary contains about 33,000 turns of about 42 miles (about 68 km) length of conductor.

On Aug. 15, work was begun upon two transformers which are not yet finished, but of which some information can be given. Fig. 2 shows one coil of the secondary winding, which contains 280 turns of double cotton-covered wire having a section of copper of .004 in. x .05 in.

These transformers have been given a preliminary rating of 200,000 volts, but have been designed along lines which should

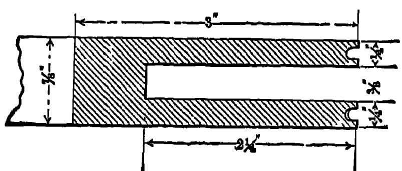


FIG. 5.

permit of their operation at potentials considerably above this value.

One of the transformers is provided with a removable yoke so as to permit of its experimental use as an induction coil of large output, when so desired, and both transformers have been provided with extra leads so as to permit of a variety of combinations for experimental work at the Institute on single, two and three-phase circuits of very high potential. One hundred coils, such as the one shown in Fig. 2, will constitute the secondary winding of each of these transformers, so that each secondary will have a length of about 25 miles (about 40 km) of wire.

DISCUSSION.

CHAIRMAN SCOTT: The work which has been done by Prof. Smith and his students is certainly of very great interest and they are to be congratulated upon its success. The paper is a record of the work which has been done, and unless we go into the general construction of transformers of this kind it is hardly worth while to enter into a discussion.

Prof F. G. BAUM then presented his paper on "Long-Distance Transmission and Control."

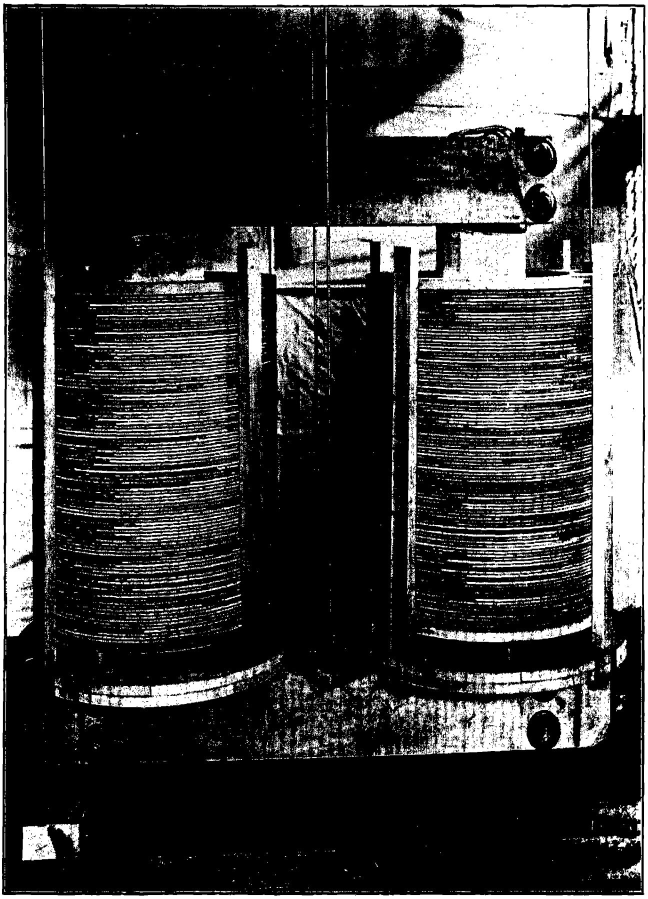


FIG. 7.— SIDE VIEW OF 200 KW, 300,000-VOLT TRANSFORMER, 1904.

HIGH POTENTIAL, LONG DISTANCE TRANSMISSION AND CONTROL.

BY F. G. BAUM.

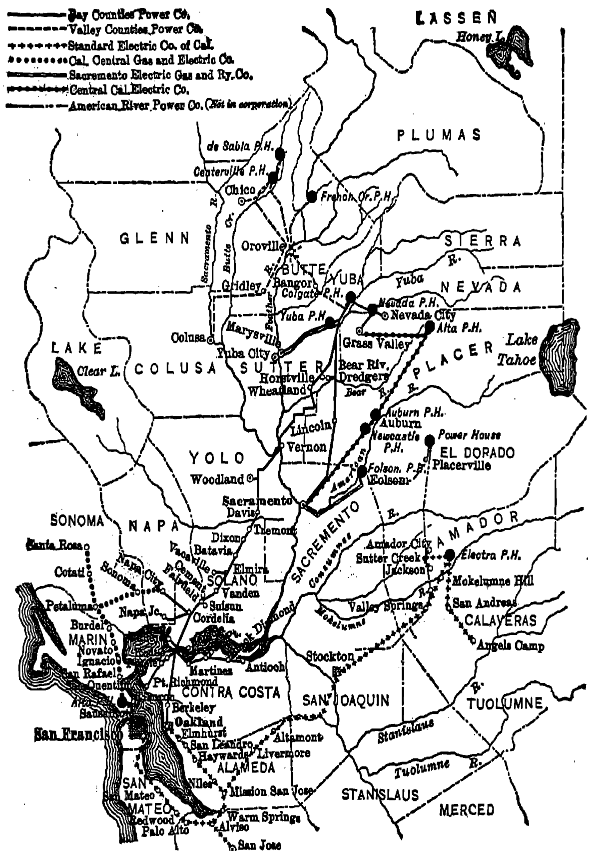
INTRODUCTORY.

In 1900, at the General Meeting of the American Institute of Electrical Engineers, I presented a paper entitled "Some Constants for Transmission Lines," based on measurements made on several transmission lines — the longest that had been built up to that time. Since then I have followed very closely the progress of transmission work, and in this paper I will give the practice and results on what is, and has been since 1900, the greatest transmission system in existence.

The system to which I refer is that of the California Gas & Electric Corporation, which has absorbed the Bay Counties Power Company, the Standard Electric Company of California, the Valley Counties Power Company, the Sacramento Electric, Gas & Railway Company, the Yuba Electric Power Company and the Nevada County Electric Power Company. The accompanying map will give some idea of the system.

The system has continuously in operation about 700 miles of line at 50,000 volts, 70 miles at 40,000 and a great many miles at 23,000, 16,000, 10,000 and 5,000 volts. The high-voltage lines extend from the Sierra Nevada Mountains of California to the Bay of San Francisco, and are thus exposed to all sorts and conditions of weather. In a short time some of these lines will be operating at 60,000 volts. The longest distance to which power is regularly transmitted is 200 miles, most of the power being transmitted 150 miles. The amount of power available on the system is 43,650 kw, and this will soon be increased by the addition of two 5000-kw generators at Electra. Owing to the large day motor load the peak on the system is not above 25 per cent of the average load.

In this paper I will give as briefly as possible some simple



MAP OF HIGH-TENSION TRANSMISSION LINES OF CALIFORNIA GAS & ELECTRIC COMPANY. LINE FROM COLGATE TO OAKLAND IS IN DUPLICATE.

methods of line calculation, and deal with the means of controlling the power at the high voltages.

PART I. LINE CALCULATIONS.

The theory of the transmission of electrical energy over commercial distances is quite simple, and at present better understood than formerly, but there is still more guess work than there should be. As all long transmission work is three-phase, this is the only system which need be considered.

1. *Circuits.*—In making three-phase line calculations, it is generally simplest to consider one leg of the system, assuming it to have neutral return with no resistance or reactance. Generally, high voltage systems are operated with grounded neutral, but whether the neutral is grounded or not we may consider the quantities between one line wire and a real or assumed neutral. The wires will be assumed as arranged on the corners of a triangle.

2. *Charging or Capacity Current.*—In the paper referred to above, I showed that the line capacity of a three-phase line is star connected, the capacity of each wire to neutral being given by the equation —

$$C = \frac{1}{2 \log_\varepsilon \left(\frac{d}{r}\right)}$$

in electrostatic units per centimetre of circuit, d (distance between wires) and r (radius of wire) being taken in the same units. We then have, at a voltage E between wires and frequency f

$$\text{Charging current per mile of wire} = \frac{E\, C\, 2\, \pi f}{\sqrt{3}\, 10^6}$$

(The charging current of a three-phase line is $\frac{2}{\sqrt{3}}$ times, or 15.5%, greater than the charging current of a single-phase line with the same voltage and distance between wires).

In Curve II., Fig. 1, is given the charging current in amperes per mile per wire with 10,000 volts between wires, the frequency being 60 cycles. From this curve the charging current for any line at any voltage or frequency may be calculated in a very few moments. Add 2% to the value obtained for a No. 2-0 wire, 4% for No. 4-0, etc., and subtract 2% for a No. 1 wire, 4% for a No. 2, etc. This rule practically holds for a half dozen sizes on either side of No. 0, for which the curve is calculated. This will include all sizes commonly used.

For wire, 3/4″ in diameter, spaced 12 feet, the charging current is 0.0331 amperes per mile with 10,000 volts between wires. This is 4% less than for No. 0 wire spaced 48″. Curve I gives the inductance per mile per wire at 60 p.p.s. For single-phase or two-phase, multiply by 1.15. For single-phase or two-phase, multiply the values of curve II by 0.87.

3. *Reactance Pressure.*—The self-induction in C.G.S. units per wire per centimetre may be calculated from the expression,

$$l = 2\left[\log_\varepsilon\left(\frac{d}{r}\right) + \frac{1}{4}\right];$$

and the self-induction in henrys per mile per wire from the expression —

$$L = \text{henrys per mile} = 0.000{,}322\ [2.303\ \log\left(\frac{d}{r}\right) + .25].$$

The percentage reactance pressure for a given current, *I*, at a given

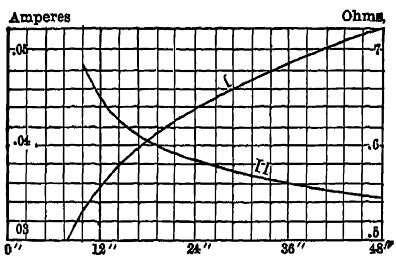


FIG. 1.—INDUCTANCE AND CHARGING CURRENT, NO. 0 WIRE.

frequency, *f*, may be calculated from the expression, *X* being the length of line in miles,

$$\frac{X L\, 2\pi f I}{\frac{E}{\sqrt{3}}} \times 100.$$

We see that in the formula for the reactance pressure we always have the ratio of the voltage between wires and length of line in miles. Assuming a given number of amperes flowing in the line, say 100, we may construct a curve between the percentage reactance pressure and the ratio of volts to length of line in miles $= E/X$, This has been done in Fig. 2, from which the percentage reactance pressure for any given case may be quickly determined. Curves are given for 12″, 24″ and 48″ between the wires. The results are given for a three-phase line with 100 amperes per wire, fre-

quency — 60 p.p.s., size of wire, No. 0, B. & S. These curves bring out in a striking way the effect of reactance in the line, and the difficulties of regulation in long lines. For any other current, multiply the percentage reactance pressure by $I/100$; for any other frequency multiply by $f/60$. For a single-phase, or two-phase system, multiply the percentage reactance pressure by 1.15. For No. 1 wire multiply the percentage reactance pressure by 1.02; for No. 2 wire, multiply by 1.04, etc. A great deal of labor may be saved by becoming familiar with the use of Fig. 2, in which the abscissæ are the ratio of E to X.

Example.—Voltage between wires — 50,000; distance between wires — 24″; length of line 100 miles. Then $E/L = \frac{50{,}000}{100}$, and from the curve, Fig. 2, we find the percentage reactance pressure for 100 amperes $=$ 22.1. The reactance pressure in volts per loop will be $.221 \times 50{,}000/\sqrt{3} = 6390$ volts per wire.

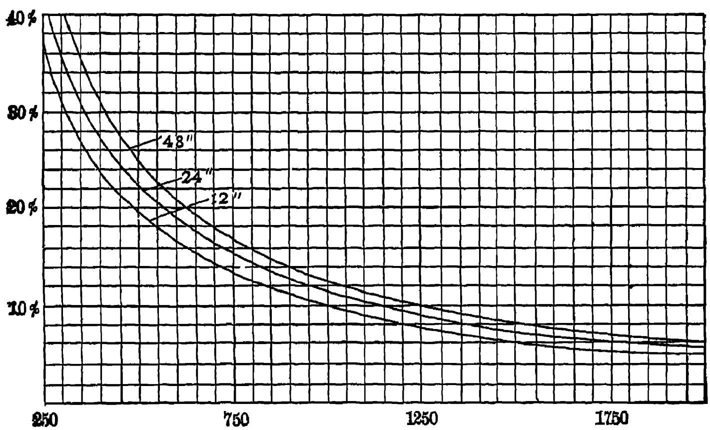


FIG. 2.— PERCENTAGE REACTANCE PRESSURE.

These curves furnish a method of quickly determining the percentage reactance pressure. For each size larger than No. 0 we subtract 2% from the values given.

Rise in Pressure Due to Charging Current.— It was shown in the paper first referred to that for all practical purposes the capacity of the line may be considered concentrated at the center of the line. This being the case, the rise in pressure is due to charging current flowing over the line reactance from the generator

to the center of the line and, hence, may be calculated by the expression: Rise in pressure $= \frac{x L 2 \pi f}{2}$ (charging current), and the percentage rise in pressure will be this value divided by the line pressure and multiplied by 100. As the charging current varies as the line pressure the *percentage rise* in pressure is, therefore, independent of the line pressure.

4. *Regulation of Transmission System.*— Of prime importance is good regulation, it being impossible to give satisfactory service unless the ordinary fluctuations of voltage can be kept within 5%. This is not difficult with large induction motors, if the motors carry a fairly steady load. By large motors I mean from 500 to 1,000 hp. Smaller motors may have varying loads and not cause any noticeable fluctuations with lines 150 miles long operating at 50,000 to 60,000 volts. The most difficult load to handle is a large electric railway load having no storage battery. The only way to handle such a load successfully is to use automatically compounded synchronous motors. In this way street railway loads of any size may be handled by the same line supplying the lighting.

Since the method of calculating the regulation of a transmission system, as ordinarily carried out, is exceedingly laborious, a method[1] is here given which is very simple.

Taking the lost pressure over the system as a whole, we are always concerned with three pressures in any case: (1) The receiver pressure, (2) the lost pressure over the line, (3) the pressure delivered to the line. The lost pressure is made up, in any practical case, of the resistance pressure and the reactance pressure. When, as is generally the case, we have receiver loads of different power-factors, we get simpler results if we consider the total receiver current divided into two parts, one the power component and the other the wattless component of the receiver current, and regard each as flowing separately over the line.

If I is the total receiver current and θ the angle of lag of the receiver current behind the receiver pressure, the power component of the receiver current is $I \cos \theta$, and the wattless component is $I \sin \theta$, ($\cos \theta$ is the power-factor of the receiver circuit; for a non-inductive load $\cos \theta = 1$; and $\sin \theta = 0$.). Let $E = oa$,

1. "A Simple Diagram Showing the Regulation of a Transmission System of Any Load and Any Power-Factor." By F. G. Baum. *Electrical World and Engineer*, May 18, 1901. Also "An Alternating Current Calculating Device," by F. G. Baum.

Fig. 3 represent the receiver pressure. The pressure consumed by the line resistance and reactance due to the power component of the load current is $I \cos\theta \sqrt{R^2+(L\omega)^2}$, in which R is the resistance and $L\omega$ is the reactance of the line. In Fig. 3,

$$ab = I \cos\theta\, R$$
$$bc = I \cos\theta\, L\omega$$
$$ac = I \cos\theta \sqrt{R^2+(L\omega)^2}.$$

Ab is 8% of the receiver pressure; that is, the I^2R loss in line is 8% at full non-inductive load.

In Fig. 3, *ac* represents, then, in magnitude and direction, the pressure consumed over the line by the power component of the receiver current. If for a lagging current we make the angle

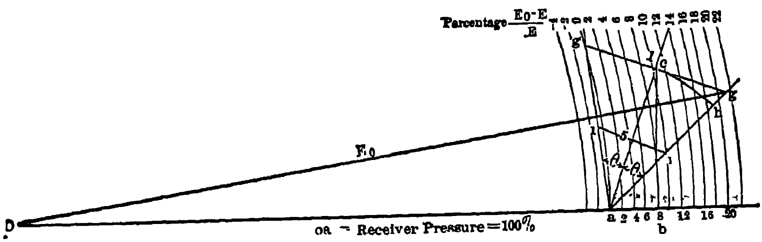


FIG. 3.— SHOWING METHOD OF DETERMINING REGULATION.

$cag = \theta$ (θ is the angle by which the receiver current lags behind the receiver pressure), and the angle $acg = 90°$, then

$$cg = I \sin\theta \sqrt{R^2+(L\omega)^2},$$

as can be proved by simple geometry. That is to say, *cg* represents in magnitude and direction the pressure consumed over the line by the wattless component of the receiver current. (If the receiver current leads the receiver pressure by the angle θ, the *cg'* is equal to the pressure consumed by the wattless component of the receiver current.)

It should be particularly noticed that the pressure consumed by the wattless current is at right angles to that consumed by the energy current. Notice also that *ac* is proportional to the power current, and *cg* to the wattless current. The true direction of the power current is along *E*, and the wattless current at right angles to *E*,— downward for lagging, upward for leading current. The line *ag* therefore represents in magnitude and direction the pressure consumed over the line by the total receiver current. Hence, *og* represents *Eo*, the pressure delivered to the line, in magnitude and

direction. *Ac* represents the pressure consumed by full-load non-inductive current. Then *ac*/2 will represent half-load on line, etc. For half-load, and the same angle as before, *E* is given by *oi*. Through *c*, with *a* as center, a circular arc has been drawn. At full-load current, and a power-factor corresponding to the angle θ, the value of *E* is given by *oh*.

With θ as center, circular arcs have been drawn through *a*, 2, 4, etc. The radial distance between two successive arcs is 2% of the receiver pressure. We see, as shown by the point *c*, that the

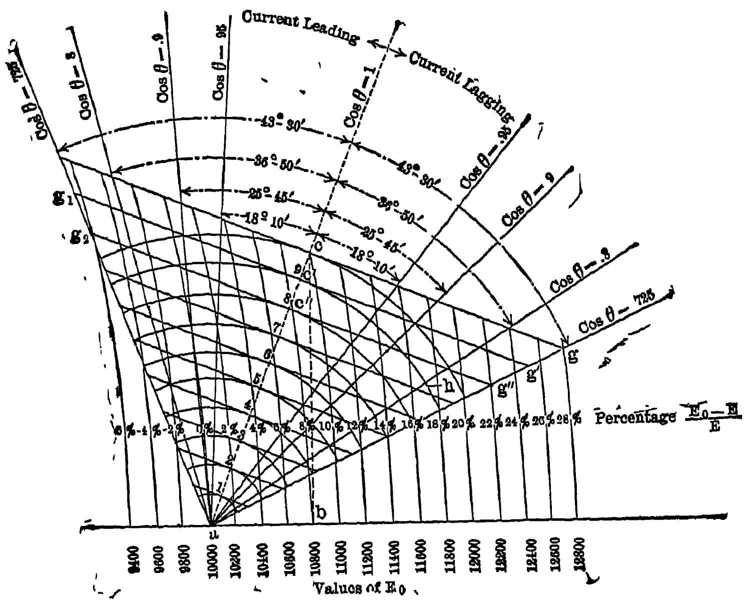


Fig. 4.—Showing regulation of 15-mile transmission system.

regulation of this system for full non-inductive load is 11%; that is, the generator pressure must be 11% higher than the receiver. At full kilowatt load, at a power-factor corresponding to the angle θ, the regulation is 21%, as shown by the point *g*; at full kilovolt ampere load; that is, for the same current as before delivered at the same power factor, the regulation is 19%, as shown by the point *h*.

In Fig. 4 is shown a case corresponding to a 15-mile transmission line, for a receiver pressure equal to 10,000 volts (the point *o* is not shown); *ac*, which represents full load, has been divided into ten equal parts, corresponding to 0.1, 0.2, etc., of full load.

Through points marked 0.1, 0.2, etc., lines have been drawn at right angles to *ac*. Radial lines making angles corresponding to $\cos\theta = 0.95$, $\cos\theta = 0.9$, etc., for lagging and leading currents, having been drawn from *a*. Circular arcs, with the point *a* as center, have also been drawn through points along *ac* marked 0.1, 0.2, etc. The regulation for any load and any power factor may be determined from the figure.

For example, to find the regulation at full load at 0.8 power-factor, go along *ac* to $c' = 0.9$, then along $c'g'$ to the intersection with the line $\cos\theta = 0.8$. The regulation is seen to be about $21\frac{1}{2}$%. For 0.9 full-load current and the same power factor, the regulation is 17%, as shown by the point *h*. It is seen that for any given case it is only necessary to determine the triangle *abc*; the remainder of the figure is drawn mechanically.

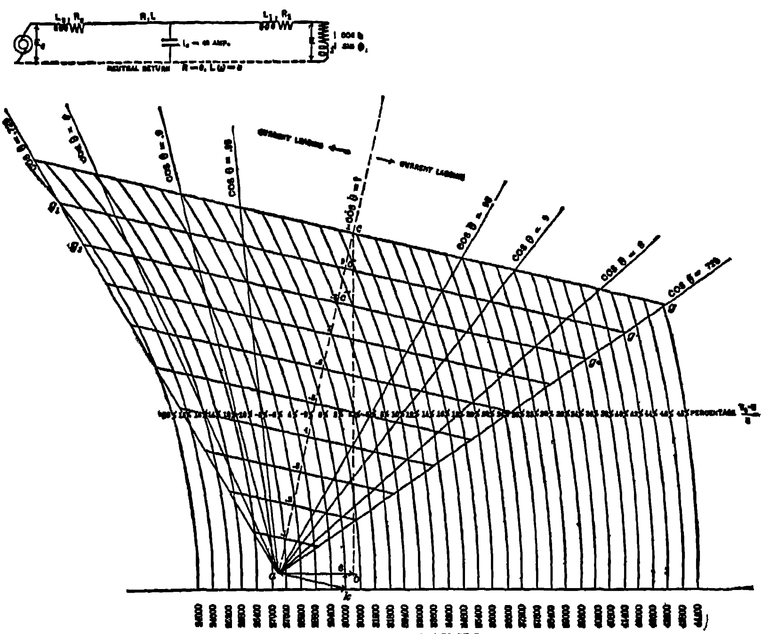


FIG. 5.—SHOWING REGULATION OF 150-MILE TRANSMISSION SYSTEM.

Fig. 5 shows the regulation of a 150-mile, 60 p.p.s., three-phase line for any load and any power-factor, with 30,000 volts between neutral and line wire, giving 51,960 volts between wires. The power transmitted is 3000 kw per leg, or a total of 9000 kw.

The small triangle *Kea* shows the rise in pressure due to the charging current. The regulation of the line for any load at any power factor is clearly shown. At no load, with 27,500 at generator, we get 30,000, or full voltage, at receiver, or a rise in pressure of 9%. The effect of a synchronous motor load of any character may be determined from the figure.

5. *Electrical Surges.*—We cannot avoid an occasional short-circuit on the high-voltage line. These shorts cause a heavy current to flow over the line, and the breaking of this current sets up surges which cause a rise in voltage that may be two to three times the normal operating voltage. The subject has been discussed by Mr. C. P. Steinmetz, Dr. A. E. Kennelly and Mr. P. H. Thomas. A simple method is here given, the matter having been first presented at the annual meeting of the Pacific Coast Transmission Association in 1902.

The subject is an interesting one to us, as we have all seen lightning arresters fused on account of the sudden opening of a circuit. I shall attempt to put the matter as briefly as possible, and in such a form that the rise in potential which we may get under the worst conditions may be easily and quickly determined. The most important case of opening a short circuit under load will be discussed.

Opening a Line Under Load or Short Circuit.—Let us consider the case of a long line with a receiver load concentrated at the end. The line capacity will be assumed equivalent to a single capacity at the center of the line. We will consider one leg of a three-phase system. The self-induction of one wire from the generator to the center of the line, that is, up to the assumed location of the capacity, is L, and the capacity of the entire line as a condenser is C (C being the capacity between one line wire and neutral). A current, I, flows over the line and is suddenly interrupted. As is well known, the energy stored up in the magnetic field (due to the current I), between the generator and the center of line is $LI^2/2$. If the current is suddenly interrupted, this energy must flow into the line condenser, since there is no other outlet. (It should be noticed that when the receiver is opened, the line condenser is in series with one-half the line and the generator.)

If V is the resulting potential across the line condenser the energy stored up in the condenser is $CV^2/2$. But this is the

same amount of energy which was previously stored in the magnetic field, neglecting the small loss due to the current flowing over the line resistance in flowing over the line into the condenser. Therefore,

$$LI^2/2 = CV^2/2 \text{ or}$$

$$I = V\sqrt{C/L} = VC\frac{1}{\sqrt{LC}} \qquad (1)$$

The current produced in a condenser of capacity C by an electromotive force having a frequency f is equal to $E\,C\,2\,\pi\,f$.

Comparing terms with (1) we see that $\frac{1}{\sqrt{LC}} = 2\,\pi\,f$, in which f is the frequency of the current in the condenser. Equation (1) may therefore be written

$$I = VC\,2\,\pi\,f \qquad (2)$$

in which f is the natural periodicity of the line. What really happens then when we interrupt the current I, is that the same current, having its natural outlet cut off, flows into the line condenser and charges the line. But the line condenser cannot remain charged, and, therefore, the condenser discharges again into the line self-induction, and the energy again is in the form of magnetic energy. The magnetic field, then, again breaks down, giving up its energy to the capacity and the whole cycle is gone over again and again, until the resistance of the line consumes the energy originally stored in the line self-induction. The frequency of the give-and-take of energy between the capacity and line self-induction is determined by the natural periodicity of the circuit f. The frequency of f in the equation (2) is therefore the frequency of the current I, after this current has been interrupted at the receiver. If the circuit is working normally at a frequency f', the current I changes from a frequency f' to a current of frequency f, that is, from the normal impressed period to the natural period of the circuit.

The natural periodicity of a circuit may be easily found from the equation

$$2\,\pi\,f = 1/\sqrt{L\ C}$$

$$f = 1/2\,\pi\sqrt{L\,C} \qquad (3)$$

For a three-phase transmission line we may take the self-induction for one-half the line, for one wire, as .08 henries per hundred miles, or $L = .08\ D$, D being the length of line in hundred miles. C may be taken as two microfarads per hundred miles, or $C =$

$2\ D/10^6$ farads. Substituting for C and L in equation (3), gives us approximately

$$f = 400/D. \qquad (4)$$

This frequency will not differ much for different distances between wires, because an increase in the distance will increase L and decrease C, the product remaining nearly the same. The same is true for different sizes of wire. That is, a line 100 miles long has a natural periodicity of about 400; a 200-mile line a periodicity of 200, etc. If we are operating normally at 60 cycles, a 200-mile line has a natural periodicity of little more than three times the frequency of operation.

From (2) we get the potential across the line condenser due to interrupting the current I equal to

$$V = I/C\ 2\ \pi f. \qquad (5)$$

Substituting for C the value $2D/10^6$, and for f the value $400/D$, we get the simple equation

$$V = 200I \text{ (approximately)}. \qquad (6)$$

That is, the rise in potential due to the surging current is, as a first approximation, independent of the length of the line and equal to 200 times the interrupted current in amperes. If I is equal to 100 amperes (141 amperes maximum), and the current is interrupted when it has its maximum value, then

$$V = 200 \times 100 \sqrt{2} = 28{,}200 \text{ volts.}$$

Interrupting 200 amperes would give us double this rise. This electromotive force will be superimposed on the line electromotive force, so the maximum strain possible for any interrupted current is

$$\text{Maximum strain} = E \sqrt{2} + 200\ I \sqrt{2}.$$

E is the voltage between line wires and neutral, and I is the current in amperes interrupted. It has been frequently noticed that a line having been short-circuited, and the short circuit broken, the arc will frequently re-establish itself or a new short start at some other place between points across which the line voltage could not jump. The superposition of the oscillating electromotive force due to the removal of the short circuit to the line electromotive force is no doubt the explanation. We have assumed that the current is instantly interrupted. An arc will always be formed which will reduce the rise in potential.

On account of the inductive drop over the line, it is very probable that the current to be transmitted over one wire of a long distance transmission (150 to 200 miles) must be limited to about 100

amperes, unless the frequency is reduced below sixty. One hundred amperes, at sixty cycles, transmitted over a line 200 miles long gives us an inductive drop of about 50 per cent, with 50,000 volts between wires. The generators will probably deliver four times full-load current as a maximum on short circuit. A short-circuit in the center of the line would, therefore, give us about twice full-load current, so that the maximum rise in potential due to the interruption of the short circuit would be about 56,000 volts. If the line is operating at 30,000 volts (equals 30,000 $\sqrt{2}$ maximum) between neutral and line wire, the strain would be a little more than twice the normal. Under certain conditions a greater rise may take place.

It seems, therefore, that there is a limit to the amount of power that can be transmitted over a line, which limit is fixed by the insulation factor against the surge voltage. If we reduce the frequency of the transmitted current to 25 or 30 cycles, so that we could transmit, say, in the neighborhood of 500 amperes over a single line without having excessive reactive drop, then we must insulate for the normal working pressure, say, 30,000 plus the surge voltage, which in this case would mean insulation to withstand a voltage of 185,000 volts as shown below—

$$\begin{aligned}\text{Strain} &= 30{,}000\sqrt{2} + 200 \times 500\sqrt{2} \\ &= 130{,}000\sqrt{2} \text{ volts} \\ &= 185{,}000 \text{ volts.}\end{aligned}$$

In other words, we must make our insulators and transformers stand a repeated momentary pressure of about 200,000 volts.

To transmit the same power at 60,000 volts, reducing the current transmitted to 250 amperes, would cause a smaller total strain due to the surge. The enormous strains introduced when we come to transmit from 25,000 to 100,000 K.W. over a single line will require extraordinary insulation against rupture due to the line surges.

In the above we have assumed a long trunk line with a receiver at the end. When the receiver current is interrupted the line current is forced into the condenser. On our long lines, however, we usually have loads distributed along the entire length, and if there is a load on at different points the line discharges a portion of its energy into the local distributing circuits, and the rise in potential is therefore limited.

The amount of energy stored in one-half of a 100-mile line is

quite small, yet it may do considerable damage. For 200 amperes it is

$$L\,I^2/2 = \frac{.08\,(200)^2}{2} = 1600 \text{ joules;}$$

that is, 1600 watts for one second.

We see from the above that the most dangerous condition is brought about when we suddenly open a short circuit. Curve I. in Fig. 6 shows the calculated oscillating potential due to interrupting 150 amperes on a line about 130 miles long. Curve II. shows the generator potential (60 cycles) and Curve III. the resultant line potential. The line voltage is 25,000 between neutral

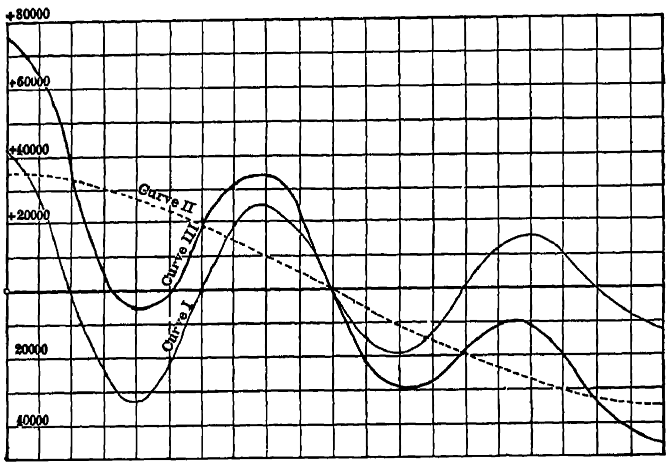


FIG 6.— SURGE VOLTAGE ON TRANSMISSION LINE.

and live wire. The current is interrupted so as to produce a maximum rise of potential.

The resultant potential, we see, is very different from the impressed generator pressure. If we continue to lengthen our lines until the natural periodicity of the circuit becomes nearly equal to the impressed periodicity, it is very probable that we will have some new problems to solve. It may be that this will prove the determining factor which will limit the distance of transmission.

PART II. HIGH POTENTIAL CONTROL.

1. *Insulators.*— We have on our lines practically every type of insulator manufactured. We have glass insulators, porcelain insulators and combinations of porcelain and glass having from one

to four parts. In the mountains and away from the fog, a 7-inch glass does very well on 40,000 volts, but to go from 40,000 to 60,000 requires that the insulator be increased more than the proportionate increase in voltage. The insulator shown in Fig.

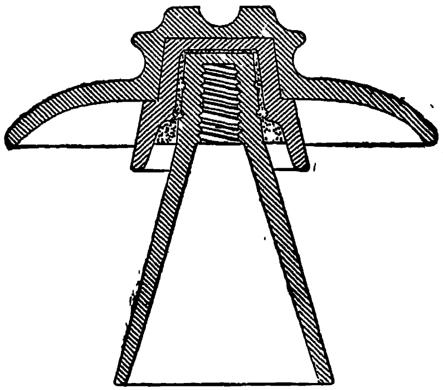


FIG. 7.—40,000-VOLT 11-INCH PORCELAIN INSULATOR.

7 is used up to 50,000 volts, but at this voltage it gives trouble in the fog districts and during wet weather. Insulators of the types shown in Figs. 8 and 9 give very good results and are probably

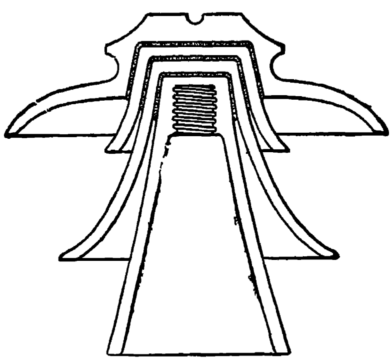


FIG. 8.—60,000-VOLT, 14-INCH PORCELAIN INSULATOR.

as good as can be obtained at present. Fig. 9 has been designed by the engineers of the California Gas & Electric Corporation.

As the time will probably come when 100,000 volts will be as common as 10,000 is today, we have not yet reached the limit of development in line insulation.

In testing the insulators, each part is subjected to more than the normal voltage from line to ground. The top is generally tested to 55,000 volts, the center to 45,000 and the middle petticoats to 40,000 volts. The test is made with salt water as electrodes.

2. *Pins.*— We are using iron pins on all our new work, and believe the idea of depending on the pin for insulation is wrong. Place the strain where it belongs — on the insulator. We are making our pins of pipe drawn down at one end. The pins are galvanized and a lead thread then cast to fit the insulator.

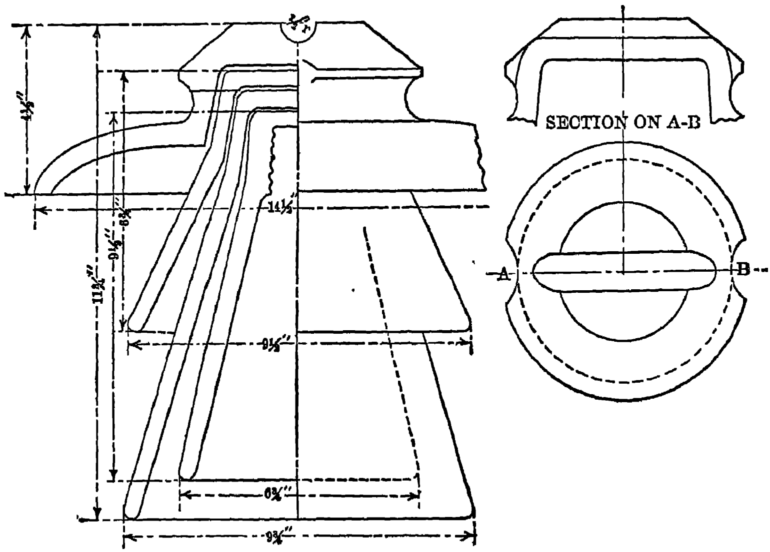


FIG. 9.— 60,000-VOLT, 14-INCH PORCELAIN INSULATOR.

3. *General Line Construction.*—We are constructing our 60,000 volt lines with a 6 ft. spread, the wires being on the corners of a triangle. On our late work we are using tall poles and spreading about double the distance ordinarily used. In the mountains where we can take advantage of the hills and ravines, we use long spans, having some aluminum spans of 1000 to 1800 ft. in length.

A tower construction using a span of about 500 ft. would make an ideal line, and a line not much more expensive and much easier to care for than the ordinary pole line.

Our method of entering buildings is through a piece of plate glass about 24 inches square having a hole about 3 inches in diameter through which the wire passes. The glass is held by a

simple wood frame. This construction is more satisfactory than the old method of passing through terra-cotta pipes.

4. *Line Operation.*— The lines are operated by keeping men at important points who patrol the lines from one to three times a week, depending on the condition of the line, these men being ready at all times to go out in case of emergency.

Our line troubles have been due to a few weak insulators; in some localities we have a good many insulators shot off. Some of our unexpected causes of trouble have been cranes or geese flying into the line; cats climbing up on the poles; green hay carried by wind dropped on the line; an engine starting up under the lines; a long tailed rat crossing temporary bus-bars.

5. *Transformers.*— Our transformers have given us very little trouble and are really the most satisfactory part of the system. High primary insulation and care in the handling of the oil to keep it free from dirt and moisture are of prime importance. The windings should be dried out before adding the oil.

That the presence of the oil does not increase the fire risk was amply demonstrated by a fire at the Colgate station in March, 1903. The transformers were in the hottest part of the fire and were damaged but little, the oil acting as a protection to the winding. The transformers were not responsible for the fire, as was reported at the time.

On test, the primary of each transformer should stand a test about equal to double the star voltage for which the transformer is designed. That is, a transformer which is to be connected 30,000 star, giving 51,960 volts line pressure, should stand an insulation test of about 100,000. Some manufacturers put on a test voltage from two to three times the transformer voltage. Less than two and one-half is not a good test.

6. *Switches.*— We find it convenient to use two types of switches to handle the electrical energy, the oil type and the air type. That the oil type switch is the only one that will stand heavy duty has been amply demonstrated. As it has not been possible to purchase satisfactory switches in the market, I have designed a line of switches for our high potential work.

We are now using the switches shown in Fig. 10 at our power houses, designed to handle from 10,000 to 40,000 kw at 50,000 or 60,000 volts. Each pole is in a separate tank and mounted in a fire-proof compartment as shown in Fig. 11. The three poles are operated together. The switch as shown gives four breaks per leg.

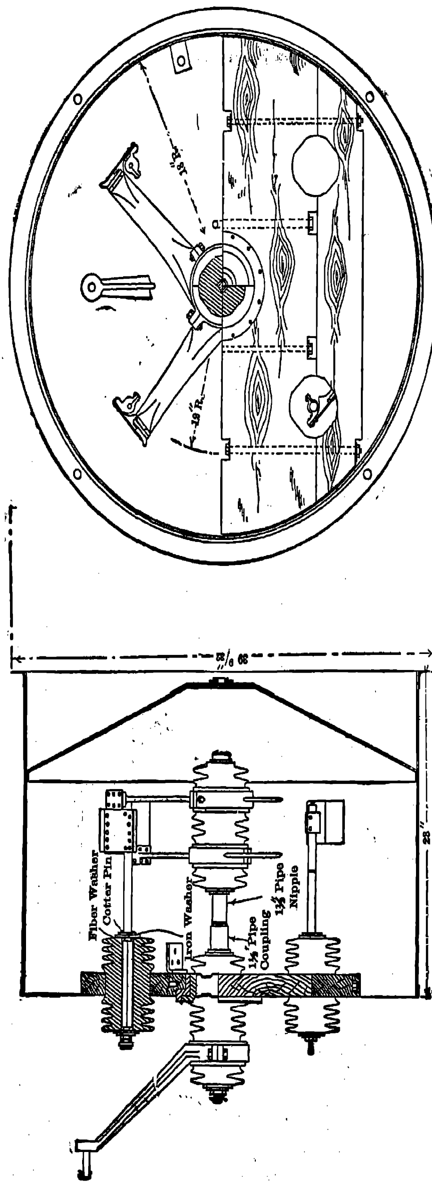


FIG. 10.—60,000-VOLT, FOUR-BREAK, OIL SWITCH.

On less important work we use the two-break switch shown in Fig. 12. This is a very simple and inexpensive design, but answers all purposes as well as more elaborate switches. Switches having the same operating principle, but mounted differently, designed by Mr. R. H. Sterling, have been in service on the system for

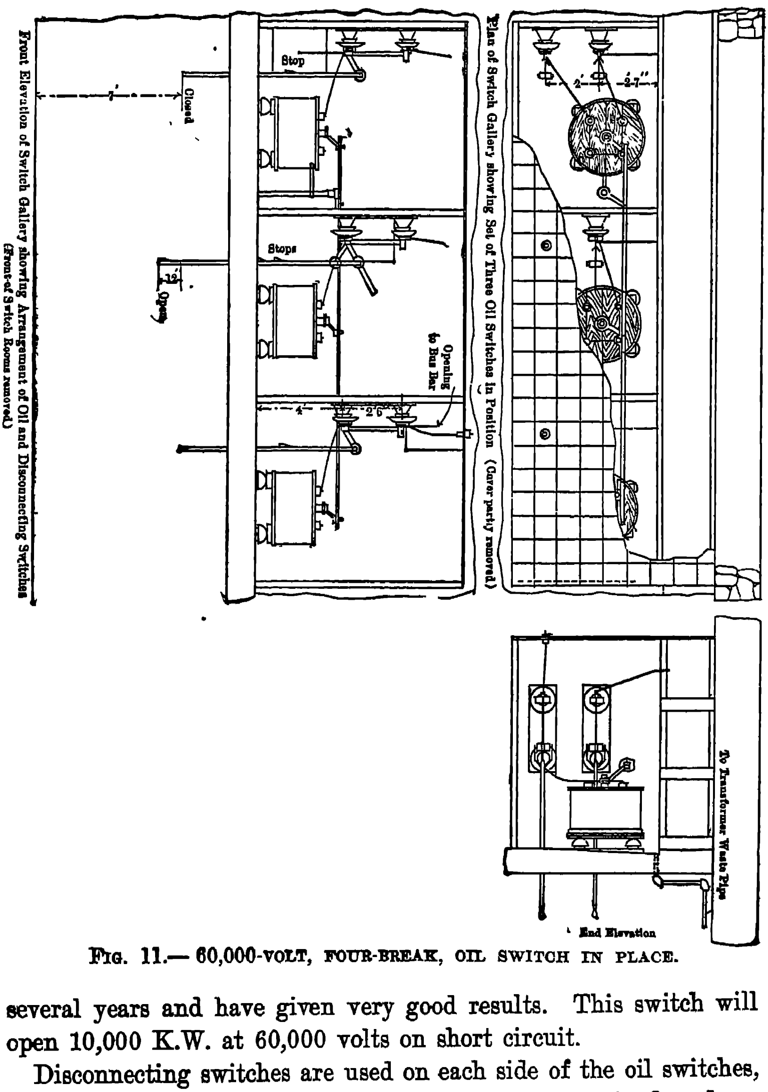


FIG. 11.—60,000-VOLT, FOUR-BREAK, OIL SWITCH IN PLACE.

several years and have given very good results. This switch will open 10,000 K.W. at 60,000 volts on short circuit.

Disconnecting switches are used on each side of the oil switches, as shown in Fig. 11, that the switch may be examined and repaired with line and bus-bars in service.

For connecting transformers to bus-bars we use three pole disconnecting switches, as shown in Fig. 13. This is a simple design and works perfectly. Fig. 14 gives a large view of the switch. As shown by Figs. 11 and 13, each bus-bar is run in a separate duct.

For an outdoor switch for substations and branch lines where the load does not exceed about 1,000 K.W., we use the switch shown in Fig. 15. The switch is mounted so that the three poles open simultaneously from a distant point.

Electrically all switches on the system are liable to have the

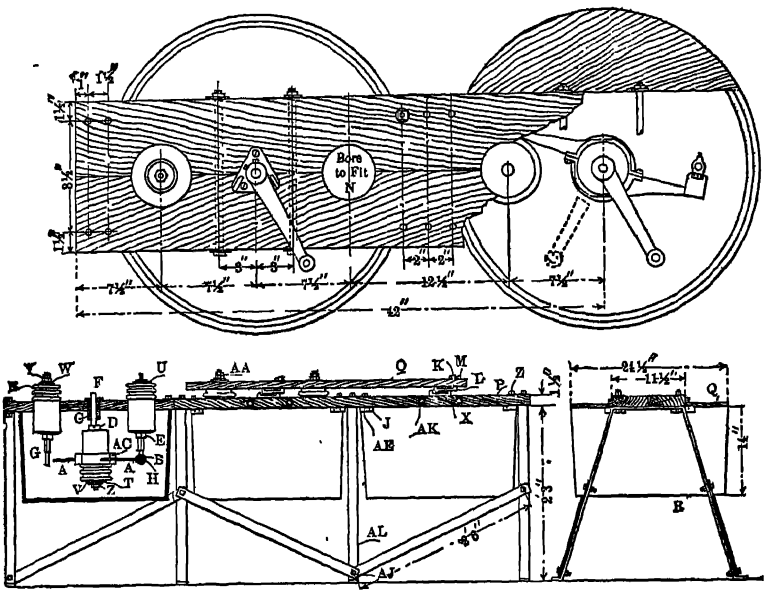
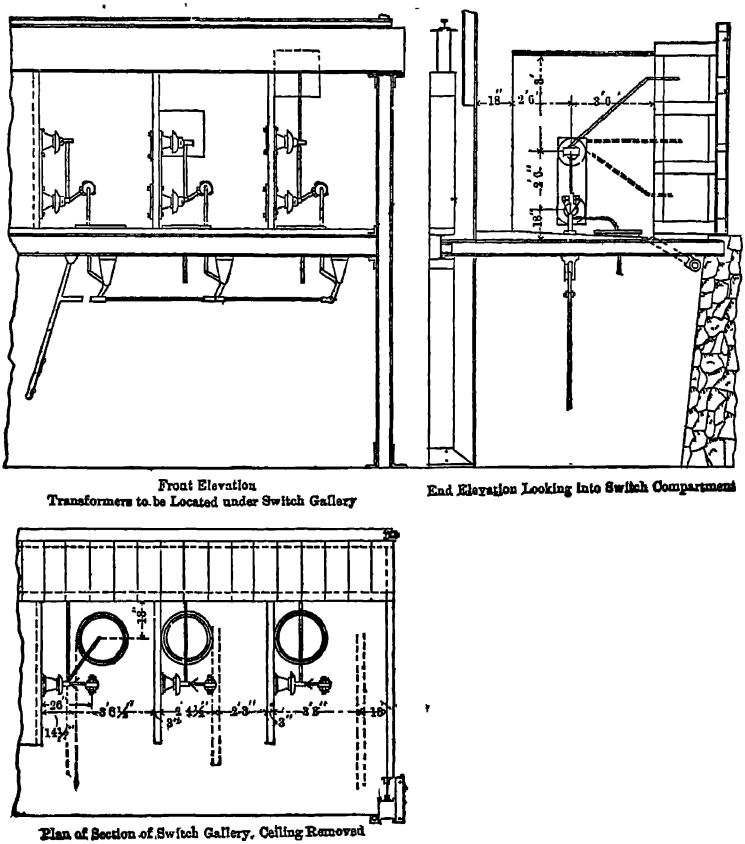


FIG. 12.—60,000-VOLT, TWO-BREAK, OIL SWITCH.

same duty to perform in case of a short-circuit beyond the switch, and some make it a practice to have all switches the same, depending on the power behind them. While this is correct electrically, the liability of trouble is slight and it is better to assume that you will occasionally burn up an inexpensive switch by trying to open on a short than it is to burn up all your money in the beginning by installating every switch of a high capacity, and at great expense.

7. *Lightning Arresters.*— For lightning protection we have decided to pin our faith to the horn arresters, these made with single



Front Elevation
Transformers to be Located under Switch Gallery

End Elevation Looking into Switch Compartment

Plan of Section of Switch Gallery, Ceiling Removed

FIG. 13.—60,000-VOLT DISCONNECTING SWITCH.

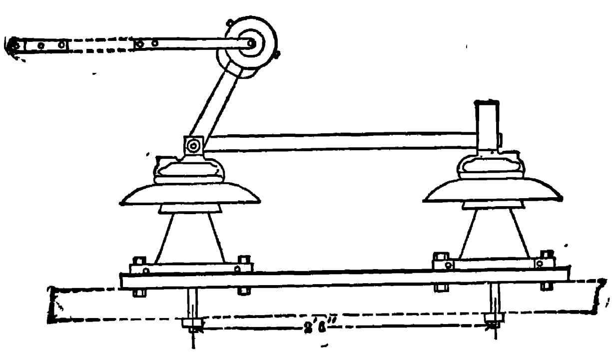


FIG. 14.—60,000-VOLT DISCONNECTING SWITCH.

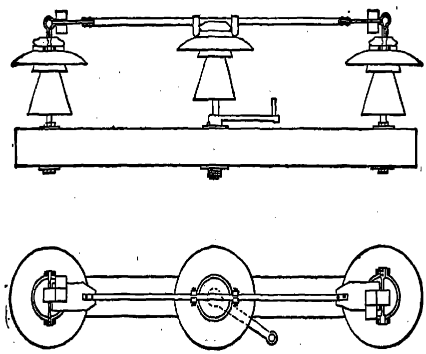


FIG. 15.—60,000-VOLT OUTDOOR LINE SWITCH.

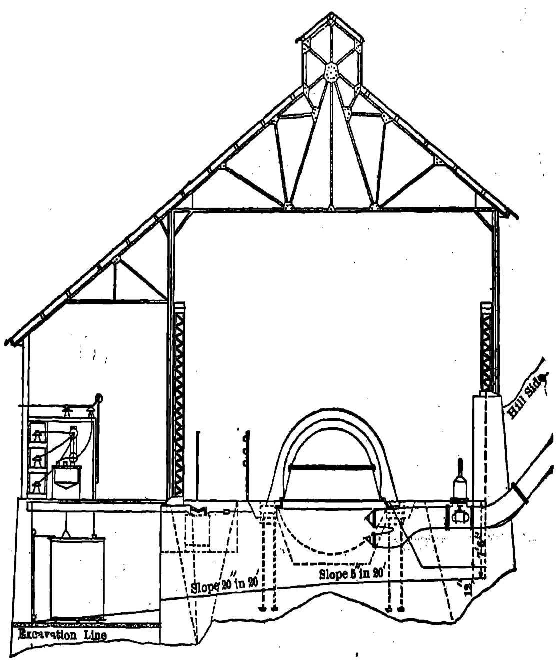


FIG. 16.—SHOWING GENERAL ARRANGEMENT OF POWER-HOUSE.

or double air gap. This simple device with good transformer and line insulation has given good results. Lightning is very often blamed for troubles that are primarily due to insufficient insulation and ignorance.

8. *General Arrangement of Power House.*— Fig. 16 shows my idea of the general arrangements of a power house in the mountains. Our high-head power stations are usually in deep canyons and the logical method of construction, it seems to me, is to take advantage of the natural slope as shown. We go from the generator through the 2300-volt switch located under the floor, then to the transformers, which are located on a lower level than the power house, with the floor left open so the operator can see the transformers and note the temperature on the dial. The floor level of the transformer room may be below the high water line. From the transformers we come up to the disconnecting switches, then through the oil switches to a second disconnecting switch to line. Locating the transformers in this way puts them in view of the operator, the practice of constructing a separate transformer room at a distance being wrong, in my opinion.

For fire walls we have the tail races between banks. I have yet to see a transformer in trouble that could not be pulled off before anything more than an injury to the coils had resulted. The switches being located in fire-proof rooms makes it impossible for fire to spread in any way. The arrangement given, it is believed, has a great many advantages, being compact, safe, easily operated and economical.

Our general practice is to generate at 2300 volts and step up to the line voltage, the primary of transformers being connected star with grounded neutral. I have come to believe the grounding of the neutral to have more advantages than disadvantages. We take advantage of the grounded neutral and very often install a single transformer in a substation, one side going to line, the other to ground; where the load is larger but does not warrant three transformers, we put in two, using two legs of the primary and open delta on the secondary. We are not bothered by any unbalancing of load at the power houses.

At the power houses we use no fuses or circuit breakers, preferring to hang on to a short rather than take chances of pulling the line off for every slight interruption. At substations the transformers are generally fused.

The size of our units has gradually increased from 300 kw, installed in 1897, to our present 5000 kw units. The 5000 kw unit is of the two bearing type with overhanging water wheel. With this type we can put 20,000 kw in a building 100 ft. long × 50 ft.

9. *Line Voltage.*— Regarding the proper voltage to be used for transmission, this will depend on conditions, mainly on the length of line. From 50 miles up it will be generally economical to use as high a line voltage as is practicable. At the present time 60,000 volts can be safely handled and 80,000 volts is not out of reach in certain localities by those experienced; and judging the future by the past we may expect to reach 100,000 operating voltage in a few years.

Our greatest trouble is occasioned by the fog. This in districts near the ocean or bay settles on the insulators and reduces the insulation to such an extent that the pins, cross-arms or poles — if of wood — are set on fire. In the mountain districts with modern insulators our line troubles are practically nil. Those without experience in the fog districts cannot realize the difficulties of insulating against a heavy fog.

The weak point of the transmission system is in the insulators. With an insulator to stand 100,000 volts, this pressure is possible.

To sum up, my experience shows that it is easier to operate a line, say from 30 miles up, at 50,000 or 60,000 volts than at 25,000 or 30,000 volts, assuming that a considerable amount of power is transmitted.

DISCUSSION.

MR. WM. MORAN: I would like to ask Mr. Baum a few questions in reference to the air gap offered between his circuit and the lighting arrester grounds. I wish to know the number of gaps.

Prof. BAUM: Well, that altogether depends, I think, on the voltage. We are now using an air gap from a line to ground of, I think, 4 inches or 4½; but it doesn't make much difference which it is. The line voltage is 50,000.

Mr. MORAN: So the sixteenth-of-an-inch per thousand stands good in your voltage, practically?

Prof. BAUM: Practically.

Mr. MORAN: Then again, what is your voltage in the metropolitan cities, if you pass through any?

Prof. BAUM: We are passing right through the city of Oakland with 50,000 volts.

Mr. MORAN: Any trouble with telephone people?

Prof. BAUM: Not with the telephone people — the politicians sometimes bother us.

Mr. MORAN: I am handling 30,000 volts and am limited on account of telephone people. A question arises, in connection with this high voltage, as to whether you are not confined by localities rather than to voltage. I am on railroad work at 30,000 volts and we were held down to 30,000 by injunctions.

Mr. N. J. NEALL: I would like to ask Mr. Baum what the difficulties are with the arresters when they operate. Suppose you have two arresters to operate simultaneously; what is the effect upon the regulation and how long does it take to extinguish the arc?

Prof. BAUM: I don't know. We hear every once in a while that some arrester has operated with a very vicious arc. Generally the power-house man does not know anything about it. We have never been shut down on account of anything of that kind. There is the ordinary drop of voltage, of course. The induction motors are affected. The synchronous motors are thrown out of step but they get in soon afterward.

Mr. NEAL: Then I assume from your answer that no two arresters are operated at the same time, and that you have not had the effect of a short-circuit over your lightning arresters?

Prof. BAUM: Oh, yes.

Mr. NEAL: You say you have nothing more than a drop of voltage at your generator?

Prof. BAUM: A drop in the voltage may have occurred. When it has occurred we had to pull off but we don't know why we pulled off. That broke the arc, if nothing else broke it; but we cannot prove that.

Mr. NEAL: Would you not, generally speaking, consider it an objectionable feature in lightning-arrester operation, that you have to pull off when your arresters operate?

Prof. BAUM: I am not sure that we have had to pull off. Until I am you cannot sell me any high-priced lightning-arresters.

Dr. F. A. C. PERRINE: In reference to this discussion, during the switching experiments that Mr. Baum just described, where they interrupted 12,000 kw with a two-break switch, the line short-circuited across two 4½-inch gaps, across horn arresters, but it burned up the arresters, the pole head and the No. O ground wire.

Prof. BAUM: That was after about the tenth time.

Dr. PERRINE: Yes, it was after about the tenth short broken by the switch when these arresters arced across.

MR. NEAL: May I ask whether you had resistance in those arresters at that time?

Dr. PERRINE: None. It was a dead short-circuit at the power-house. We were operating four 2000-kw machines, and the voltage held constant. The ammeters, at the time the switch was opened indicated a current equivalent to 12,000 kw or something beyond. Immediately after we had interrupted the circuit, the lightning arresters at the power-house short-circuited.

MR. NEAL: There was no resistance in that connection between the two arresters?

Dr. PERRINE: No resistance at all. It was a dead short-circuit between the two lines.

MR. MORAN: May I ask if you have tried the multiple-gap arrester and with what results? That is, a number of small gaps instead of one large gap.

Prof. BAUM: I don't want to say anything against any lightning arresters, but we have used every lightning-arrester that is made, I think with the exception of one. We have used every type of multiple-gap; the result is that we put them out of business, can't make them stay on the line; we burned them up.

MR. MORAN: Is that on account of static effect, running down half way on the arrester?

Prof. BAUM: No, it is current burning it up; short-circuit.

MR. MORAN: Have you any static interrupters on the line, dischargers?

Prof. BAUM: None whatever.

MR. NEALL: I would like to ask one more question in regard to these arresters. Last year when I was out visiting this line I found the horn-arresters had resistances in series with them. What time were they installed and what was the object?

Prof. BAUM: There are some that have resistances in series and some that have not. I think there are two with resistances in series and the remainder have not. We do not notice any difference in the operation of the arresters, whether they have resistances in series or not, although I prefer the resistances in series. That is, a resistance between the arrester and the ground.

Dr. PERRINE: But that is not resistance between lines.

Prof. BAUM: No.

Dr. LOUIS BELL: I would like to ask Mr. Baum where these lightning arresters were located on his line; how many of them were used?

Prof. BAUM: At various points (indicating on blackboard).

Dr. BELL: Then they are put in at discretion, at points which may seem possible danger points, and nowhere else?

Prof. BAUM: No.

Dr. PERRINE: If I understand you correctly they are only put in at terminals.

Prof. BAUM: They are put in at the power-house also.

Dr. PERRINE: They are not put in at intermediate points, are they?

Prof. BAUM: No.

MR. NEALL: What is your idea of the best resistance for an arrester of that kind?

Prof. BAUM: I havn't any particular idea.

MR. NEALL: What type of resistance are you using?

Prof. BAUM: We have a number of carbons connected in series — high-resistance carbons; some of these are immersed in oil.

Dr. BELL: How high resistance do you use in those arresters between line and ground?

Prof. BAUM: Well, I couldn't tell you exactly as I did not put in that particular resistance. Mr. Bunker is here and he could tell you.

MR. NEALL: Have you made any investigations to determine the result

on the line when one of these arresters discharges? It seems to me, looking at it broadly, if you have got to wait until your voltage rises sufficiently to leap four inches and a half, that there may be other points of your line to give way before that is reached, and the very presence of the horn-type arrester necessitates a very abrupt disturbance on the line to make it operate.

Mr. E. F. OGLE: I would like to ask a question in reference to the insulators in Fig. 7 and Fig. 8 of the paper. With the type of insulator shown in Fig. 7, have you any trouble with the snow freezing in between the petticoats, or don't you have any snow?

Prof. BAUM: We have practically no snow on our lines.

MR. OGLE: Do you have any trouble with the cement that holds them together freezing?

Prof. BAUM: No.

Mr. M. H. GERRY: Let me ask Mr. Baum a question before we get away from this lightning arrester. Do I understand Mr. Baum that he had a 10,000-kw — or perhaps 25,000-kw — capacity short-circuit on that 4½-inch gap, and that the arc broke on the arrester without the necessity of pulling off, or anything happening?

Prof. BAUM: The lighning arrester was outside.

MR. GERRY: How far from the generating point?

Prof. BAUM: Ninety-eight miles. The short-circuit produced a surge in the line, breaking down the 4½-inch air-gap. This shows a rise of voltage to something like 100,000 volts. That is, the two 4½-inch air-gaps to ground would mean somewhere around 90,000 or 100,000 volts. A number of times on this lightning arrester the arc would break with 8000 kw on the line. The last time it simply burned up.

MR. GERRY: How much capacity was on the line?

Prof. BAUM: 8000 kw of machinery.

MR. GERRY: I think there would be somewhat more capacity on short-circuiting across the lightning arrester, perhaps 15,000 kw.

Prof. BAUM: Certainly.

Dr. PERRINE: We read 12,000, 15,000 kw.

Prof. BAUM: The ammeter needle went off the scale, and the arc just simply raised up and broke.

MR. GERRY: And there was no serious drop of potential — 50 per cent, 75 per cent — across that gap?

Prof. BAUM: Well, it is a pretty difficult thing to read a volt meter on a station line in a condition of that kind, I think you will realize.

MR. GERRY: Well, if it went to anything like, say, 25 per cent voltage, it seems to me the induction motors might drop off.

Prof. BAUM: This line was simply on test at that time.

MR. GERRY: There was nothing on it.

Prof. BAUM: No.

MR. GERRY: Then it practically amounts to a short-circuit when one of those arresters goes off?

Prof. BAUM: Yes.

MR. GERRY: Then, every time the horn-arrester goes off you have a short?

Prof. BAUM: A temporary short.

MR. GERRY: Then every time the horn arrester goes off you lose your load or part of it?

Prof. BAUM: A part of it.

MR. GERRY. Then the horn arrester is simply a device that produces a short-circuit on the line at every time the current follows into the arrester?

Prof. BAUM: Yes.

MR. GERRY: And you lose your load?

Prof. BAUM: Some of the load. You must remember that we do not have these arresters going off every day. For one year now I cannot recall the lighning arresters going off once. The last time they went off was when we made this test and I can't remember them going off since.

MR. GERRY: Why don't they go off? Isn't there any lightning or doesn't it go through the arresters?

Prof. BAUM: There isn't lightning enough to bring it up to the 4½-inch gap.

MR. GERRY: Well, isn't that what breaks the line then? If the gap was larger wouldn't you have still less trouble, and if you took the arrester off all together, still less?

DR. BELL: In case a short-circuit or fault somewhere back on the line produces a short across the arresters, does that short uniformly hold for any considerable length of time? In other words, does it hold until it practically takes the arrester with it, or does it break; and if it does break how long does it take in doing it?

Prof. BAUM: Well, you can realize that in a system like this which covers five or six or seven counties, that I or one of my men cannot be at the arrester watching.

DR. BELL: I understand. But has not the action of the arrester ever been observed, to see when it breaks successfully. How long does it hold before breaking?

Prof. BAUM: In case of this arrester it broke a number of times up to a year ago. Then we moved the lines farther apart. The man would report once in a while that the arresters went off. Nobody else reported any trouble whatever. At one point a man, a year and a half ago or two years ago, reported that the lightning arresters went off.

MR. GERRY: Well, did they short-circuit?

Prof. BAUM: There was a big flaming arc. We moved the arresters a little farther apart. Since then we have had no discharge at this place, and no trouble at all.

DR. BELL: In other words, do I understand that the arresters, at least now and then, go off and operate successfully, without causing disturbance enough at the power station to say whether that break was instantaneous or whether it lasted two or three seconds?

Prof. BAUM: We don't know.

DR. PERRINE: I think in catechizing Mr. Baum on the question of his horn-arresters, we are getting away from the point of this paper, which is practically stated by Mr. Baum when he says that on such a system of

transmission as this, he would use the highest possible voltage. He is having less troublesome experience at 55,000 — which is about the voltage I understand he is running now — than he had at lower voltage, and he ascribes this largely to the relatively smaller value of the voltage when a surging current is interrupted. In consequence, he believes that it is advisable to keep down the current on the line, keeping up the voltage, for the reason that it makes these minor devices, such as lightning arresters, relatively unimportant. It is not the important point to catechize Mr. Baum on whether he has set his arresters at 3½ inches, or used mutiple gaps, or what. The point that he has made in his paper is, that by going to this high voltage and keeping his current down, he has made the minor difficulties, which have troubled us all so much, relatively unimportant. That, I think. is due not only to his high voltage on long lines; but also to the presence of multiple stations which feed into the line from all directions and which feed a very large amount of power, so that while in our discussion we may say that a short-circuit reduces the voltage on the line beyond it to nothing, we say that not knowing what actually happens. We may have a short circuit across an arrester or between lines, across a piece of bale-wire thrown on the line, which may, as Mr. Baum has stated, result in a relatively small current; so that beyond that point, if we have generating capacity enough behind us, we will still get voltage, and although we may have these minor interruptions, they will not interfere with the service. The paper of Mr. Baum is notable to me particularly in the fact that he does not discuss as difficulties many of the problems that we have been discussing in our transmission papers during the past year. For example, when the first of these lines began operation the question of the capacity effect became very important. Until Mr. Baum introduced the exciter device which he has already described to us, one long-distance transmission system could not operate a lighting load on account of troubles with capacity, and, in consequence of capacity troubles, we have often discussed the use of motor-compensators. You will notice that in Mr. Baum's paper there is not any mention of any necessity for these artificial regulating conveniences, except when the question arises of operating large street-railway plants with their variable load. So that on account of high voltage, keeping down current, and the great number of stations feeding the line from different directions and different points, a very satisfactory solution of the switching problems has been reached; as well as an apparently satisfactory approaching solution of the insulator problems. In this great system, operating a total of about 700 miles of high-potential lines, and operating two stations in parallel, 325 miles apart, he gets rid of the troubles which some stations have when carrying relatively small amounts of concentrated load of one kind, operating single lines. The success of this system is the success of a system which is operated as a whole, and it is not only the lightning-arrester difficulty which largely disappears, but it is also the capacity difficulty and the inductance difficulty and many other difficulties which also largely disappear. It is firmly my opinion that the great success of this long-distance transmission is due to its apparent complexity.

DR. BELL: I think the whole profession owes a debt of gratitude to Mr. Baum for his practical researches on these problems that have been bothering us all more or less. But apropos of what I think Dr. Perrine has just said, I cannot help feeling that there is a phase of the matter that we are justified in presenting to Mr. Baum's attention. A great system like this, the greatest transmission system in the world, may not have immunity from all troubles. When you feed from half-a-dozen points and have thirty load points, trouble no longer embarrasses the system as a whole, so that many of the difficulties are simply minor local troubles. Nevertheless, this is not a normal transmission line. It is a wonderful and exceptional one, on which Mr. Baum has been privileged to experiment. If we had instead of such a system a straightaway system of 10,000 kw for 75 or 100 miles, and the same troubles, of short circuits over the arresters, etc., came upon it, it would not mean an incident in the system; it would probably mean losing the whole load, with all that this implies. So that while these difficulties can be passed over as minor in a splendid large system with a considerable number of feeding points; they become major difficulties, perhaps controlling difficulties, under almost precisely similar circumstances as regards construction, when we deal with a single line on which anything happening puts the whole business of the company out of commission for a longer or shorter period. That, I think, is why we pressed home some of these questions which are not intended as criticisms at all, but merely to get Mr. Baum's valuable experience on some of them. As respects the high-voltage proposition, I have always believed that when you passed over the moderate, and comparatively insignificant voltages of the past, the 10,000 volts or so which was used so extensively, the proper thing to do was to play the limit fairly, and it seems to me one of the great advantages of playing the limit is not only immunity from surging — I have seen the terrific effect of it at three or four thousand volts — but the fact that when you are insulating for 50,000 volts, you are planning the details of the line with a respectable factor of safety, to which most of the minor troubles, including all the minor lighting discharges, become insignificant. In other words, when you are insulating for 60,000 volts as thoroughly as Professor Baum is insulating out there, the ordinary induced lightning flash — what we generally know as lightning on the line — is merely an incident; it is merely what might as well be a part of a surge in voltage, a part of any extra rise in voltage, but cuts no figure there with respect to the margin of insulation of sixty or seventy-five thousand volts which you have left. I think the secret of these high voltages lies not only in the dimunition of the surging troubles, which of course takes place just in that way, but also the fact that you have a tremendous factor of safety, and it gives, all of us, I think, courage in attacking the problems of the future to know of the great success which Mr. Baum has had on this big system, and the extent to which the insulation precautions, which he has taken, overcome these minor difficulties.

MR. MORAN: I would like to ask one or two more questions from Dr. Perrine and Mr. Baum. As I am not thoroughly familiar with the

systems, I wish to ask if you have one circuit on lighting and one circuit on rotary-converter power?

Prof. BAUM: All together.

MR. MORAN: What I was driving at is that I wish to try to find the relative trouble, if any, on a rotary load and a lighting load on such a long-distance system.

Prof. BAUM: The lines are operated altogether; everything is in parallel; the lighting load is taken off from the same line that the motor load is taken. Up to a year ago the Northern system was independent of the other system, and we supplied its load from one power house, which was a straightaway system, load of course being taken all along the various points. During that time we had very great success with the continuity of service. To give an instance, at one point there were two 800-hp motors driving machinery in a cement plant. We have a record of those running for 67 days without a single stop. I think that is as good as we can get in any steam plant. We have motors driving a street-railway load, and we run that very often thirty or sixty days; we sometimes get a sudden knock-out, but are back in five minutes. If they are out over half-an-hour we hear from the board of directors.

I will illustrate what we did about two weeks ago. The station at Electra entirely broke down. There was a load all along its line which made it necessary to carry everything from the other stations. The intermediate station was partly disabled. That makes a distance of 325 miles the line was put through. We started up one machine at the end, and ran it as a synchronous motor and varied its excitation, and the entire load was carried, one portion to a mine; making a total of 350 miles of stretch. The service was just as good as when we were feeding from both ends, due to the fact that we had the synchronous voltage running at the terminal and we held the voltage just as though we had the power house there.

MR. BLACKWELL: I would like to ask Mr. Baum whether all the different plants of the California Gas and Electric Corporation are ordinarily operated in parallel; or whether they each supply a different portion of the system, and are only thrown in parallel to meet emergencies?

Prof. BAUM: Just at present we are not operating them in parallel. We intend to arrange, in the course of time, so that we can at any time parallel them. They are arranged now so that you can pass a load from one point to the other. The two systems are kept separate at present so that the services from one line will not affect the service on the other. But we may change that. I anticipate when we get some insulators replaced, which we are now doing, that we will not have an interruption once in two or three months, with the modern insulators, and in that case we might as well tie the whole thing together.

MR. T. J. CREAGHEAD: I would like to ask Professor Baum about the line switch as shown on page 264. I have not dealt with the fifty and sixty thousand volt lines but on medium high-tension transmission lines. I have always had the greatest respect for any place up the pole anywhere near the cross-arm. Now, in the use of a line switch as indicated

by Professor Baum, I would like to know whether it is the intent to climb the pole and turn the switch by hand.

Prof. BAUM: The switch is operated from the ground with a single lever. The three switches are connected here with a wooden cross-bar and they are operated from the ground with a lever.

Mr. P. H. THOMAS: I wish to ask the author for a point of information. As I understand his calculation, the possible voltage rise on a line due to the interruption of a short-circuit current is made as follows: The heavy current resulting from the short-circuit stores magnetically in the inductance of the line a considerable amount of energy. On interrupting this current, this energy, is discharged into the capacity of the line. The result is a certain rise of potential, depending on the inductance of the line, the resistance and capacity and some other factors. The numerical value of this equation is based upon the assumption that the interruption of current occurs near its maximum value. What I wish to ask, is whether any experimental evidence has been derived tending to show that actual interruption of current does occur near the maximum point? I wish to call attention to the distinction between the mathematical basis of the equation stated and the rise of potential which may occur due to a resonant circuit tuned to an oscillating source of electromotive force, the latter requiring evidently a number of alternations to establish maximum potential. As far as my observation and experience are concerned, which include a number of direct experiments, no positive evidence is obtained proving that a heavy current will actually be interrupted near its maximum point within the wave.

Prof. BAUM: Mr. Thomas has got the wrong impression from the article. The rise in voltage is two hundred times the interrupted current, as I said. Take the value of the current the moment you interrupt it, and you get the rise in voltage. If you have no current, you have no rise. In other words, the current is sinusoidal. If you interrupt it at the zero line, we don't get any rise in voltage. If we interrupt it at the crest, the maximum, we have the maximum disturbance. I do not think we have any more evidence that the current will be interrupted at the crest than we have that it will be interrupted at any other point. If you throw a wire over that line, you do not know whether the final burning out is going to be at one point of the current wave more than another.

DR. PERRINE: I think the real thing Mr. Thomas is trying to get at is, whether there is any direct evidence that there is any considerable rise in potential?

MR. THOMAS: That is the point exactly.

Prof. BAUM: When we performed these experiments by short-circuiting this line a hundred miles away, we short-circuited the switch, an oil switch; the line discharged over an arrester set for 4½ inches. You can readily calculate your voltage in order to jump that air gap; about 90,000 volts; 4½ inches to ground, 9 inches between lines; short-circuit to ground. That occurred repeatedly.

MR. THOMAS: At which end did that discharge occur?

Prof. BAUM: It occurred at the power house. It would undoubtedly

have occurred elsewhere if we had other lighning arresters. It occurred at the power house because that is where we had lightning arresters. It was an oil-break switch.

Mr. Thomas: What do you conclude from that?

Prof. Baum: I conclude from that that you get a rise in voltage somewhere approximating that formula, due to an interruption, a short-circuit.

Dr. Perrine: I think there is an unfortunate double meaning to the term "resonance" as employed in the discussion. Mr. Baum is using resonance to signify the discharge due to a resonant circuit, a circuit which may not be perfectly balanced against another circuit but which at the same time is a circuit which discharges because it has inductance and capacity in it and in which the current circulating is interrupted. What Mr. Baum is giving us is what actually occurs when we interrupt a definite circuit. What Mr. Thomas described is what might occur, if we had one circuit perfectly balanced against another circuit. If this were impressed with the same frequency and voltage that are used in Mr. Baum's calculations, it would result in a very much higher increase of potential.

Mr. Thomas: The information I desire is, which is the actual explanation of our troubles?

Prof. Baum: I think that is given here.

Mr. Thomas: I was asking what the evidence was for that; that was the point I was starting out; and if that is clear then I am through. What is the evidence of that? You assume it is so?

Prof. Baum: There is nothing theoretical that can be shown, but I have never heard the thing questioned before.

Dr. Bell: As a matter of fact, when we have a circuit such as Professor Baum has indicated we have a perfectly straightforward clear case of simple resonance in a simple circuit and under those circumstances we get that rise. You can call it by any name you please. It is simply one form of resonance. The last speaker was referring to what you might call complex resonance, which I believe actually does take place on lines oftener than we think.

Mr. Neall: I wish to add to Dr. Bell's remarks that I do not wish to criticise Professor Baum for his lightning arrester, but to call attention to the importance of the lightning arrester situation in general. Abroad, where the horn-type arrester has been used very generally, there seems to be no data to show its efficiency at 50,000 volts. This system of protection has not until recently met with favor in this country, and its present employment, which is confined to very high voltages, indicates a degree of protection lacking in our regular types. For this reason we can appreciate the desirability of all possible information as to the operation of Professor Baum's 50,000-volt horn-type arrester. My question has for its object more to learn what happened to these arresters than to criticise any individual for installing them. In continuation of my series of questions, I should like to ask Professor Baum if he has lost any poles directly from lightning.

Prof. Baum: I do not think we have lost any poles due to light-

ning. We may have lost an insulator here and there, but I cannot trace and absolutely prove a single thing on our lines due to lightning.

MR. NEALL Don't you think you could have taken a record of the operation of your arresters wherever they have been installed, by putting in supplementary gaps and having your men watch them regularly, thus knowing very closely what your arresters were doing and when they did it?

Prof. BAUM: Of course, we try to get all the information we can from our system. You are no more eager for information than we are. We do not get the information primarily to present to a meeting of this kind. We get it primarily for ourselves.

MR. NEALL: I do not want to appear prejudiced, but it does seem to me that the usefulness of the horn-type arrester has not been brought out prominently. The only thing that has been brought out is that it does not do any harm to the system, but there is a very grave question whether it does any good.

Prof. BAUM: Well, I consider it a safety. It may not operate more than once in a year, may not operate more than once in two years, but even if it shuts down your system once in two years absolutely, I consider it a safety to the system.

Mr. NEALL: Do you think it is any better in that respect than other forms of arresters which will discharge at lower voltage?

Prof. BAUM: The trouble is that they discharge too often. We do not want them to discharge that way. When they discharge once they are entirely out of business; you have got to buy a new set, and you know how many there are in multiple; it is expensive to put in lightning arresters of the ordinary type. Here we just put up a lot of copper wire and there is the end of it. We could keep one freight car from the East loaded with lightning arresters of the ordinary type busy all the time. Of this kind we can buy ordinary copper wire in stock and put it up.

Mr. NEALL: Is that a matter of experience or just a matter of belief?

Prof. BAUM: That is experience. I have had lightning arresters out there by the hundreds.

Mr. NEALL: Have you tried all types of arresters?

Prof. BAUM: All types that we could get hold of.

Mr. NEALL: Then I am to infer from your remarks that you believe for the future protection of high-voltage lines that some simple form of horn arrester is the solution?

Prof. BAUM: I don't profess to have any particular prophetic vision in the matter at all. At present we are using the horn arrester. As far as I am concerned I would just as soon take them all off; but I keep them there for safety.

Mr. MORAN: I have had no experience with the horn arresters and have had some with the multiple-gap arrester; a test of forty thousand volts did not prove satisfactory to the multiple-gap arrester. If you will notice 30,000-volt lightning arresters in working condition, closed upon the line there will be seen a number of sparks constantly plying between the gap half way down the arrester, and as the surges in the line increase they

will go to ground, opening the circuit if you have any automatic arrangement in the line, so that Mr. Baum's answers indicate to me that 30,000 volts is the limit for such arresters.

Mr. Gerry: Mr. Baum remarked that the limit of transmission tension rested with the insulator. I think it does not rest with the insulator, but with the transformers and secondary apparatus, such as the lightning arresters, switches, etc. Many of the difficulties have been worked out by Mr. Baum, and he has shown that we may go with safety to somewhat higher pressures, but it seems to me that the limiting condition is still in the apparatus even more than in the line insulation. The horn type of arrester will undoubtedly do good work under certain conditions, but as Mr. Baum will concede, if the gap be adjusted so that it will discharge only occasionally, a number of small difficulties such as occur with multiple-gap arresters, will be overcome but they will then be concentrated in one considerable difficulty, perhaps an interruption of the service, which may occur but once a month or once a year, depending upon the climatic conditions. In regions where there is a great deal of lightning it may readily be seen that a horn arrester might produce most unsatisfactory results, in the way of frequent shut-downs, while in other localities the results from a practical standpoint might be acceptable. I brought up the lightning arrester question, not because I disagreed with Mr. Baum, but to bring out the facts, and having done this I wish simply to reiterate the statement that I believe the limitations of working pressure for transmission purposes to be in the lightning arresters, switches, and secondary apparatus, as well as in the transformers. These limitations are not permanent, and the difficulties they present will be overcome, but at the present time the limiting conditions are there rather than in the line insulation.

Prof. Baum: I do not agree with Mr. Gerry on most of those points. The transformers are not limited to the present voltages for which they are now being built. We are willing to build oil switches for 100,000 volts if we want them. The lightning arrester I think will take care of itself when you are operating at 100,000 volts and over; that is, if you insulate the line properly. There is nothing left, in my mind, but the line insulator, and I consider that the weak point of the transmission — the only one at which we see any very great difficulty in going to a higher voltage, say 100,000 volts. In other words, I believe if it were not for the line insulator we could go to 100,000 volts to-day.

Chairman Scott: We have had a very interesting discussion on the matter of lightning arresters, even though it be but an incidental part of the paper. I fear that some of the things Mr. Baum has said are susceptible of misinterpretation by others. If the simple statement goes forth that in operating his line he has found the simple horn arrester to be ample, and since his lines constitute the most extensive system in existence, then others may conclude, that because their lines are shorter and voltage lower, the horn arrester will be ample for them. I do not believe Prof. Baum quite intends that interpretation. In fact, he has said that he has but little lightning, and that he would not regret very much leaving them off entirely, but it was rather a matter of conscience

and sentiment that the arresters were put on, so that they might feel a little safer. The absence of severe lightning is shown by the fact that they have lost no poles by lightning. On another plant a gentleman told me a while ago that in one storm forty-seven consecutive poles were more or less affected, and that he had had large poles from which, after one good disturbance, there wasn't enough left to make a fence post. Now Prof. Baum is not talking about conditions of that kind. He has said, moreover, that something happens on the lines from time to time, and he does not know whether it is caused by the lightning arrester or not; and he suggests that these disturbances, due to lightning arresters or something else, may be eliminated so that they occur only occasionally. Perhaps in the large system there is less likelihood of shutting down due to a disturbance at one place; but there are plants in which the mere fact of a temporary shut-down once or twice a season, of perhaps only a few minutes, and involving little or nothing in the way of cost and repairs, would lead to a very grave criticism of the protective devices. So I think, in line with what Mr. Gerry has said, we must feel that the lightning arrester problem is not at all solved because there have not been more difficulties on the Bay Counties line. If the operating engineers are satisfied with a horn arrester; if that will do all that they want, the manufacturers of lightning arresters have been entirely off the track in spending thousands of dollars and the time of experts in trying to solve the problem. Some may say it is because they want to sell something; but primarily it is because of the fundamental need of something of that kind, and because they have felt there is such a need. In fact I rather think that some of those who manufacture lightning aresters would possibly be glad to be relieved of the whole problem, but it is a necessary element, and one of the most difficult in the preparation of the apparatus for transmission systems, and I rather feel that operating engineers do not want to express a sentiment which will lead to the idea that efforts in this line by those who are doing the work of investigation, and trying to prepare apparatus of this kind should be lessened. Do I state it properly, Prof. Baum?

Prof. BAUM: That is correct. I do not want to give out the impression that if I were operating in a different part of the country and I were operating at a different voltage that I would not put on the multiple-gap lightning arrester.

Chairman SCOTT: Probably put on everything you could get?

Prof. BAUM: Tried everything I could get. We have tried this here and it has gone out of service and we have tried something else.

The CHAIRMAN: Is there any further discussion of this paper. If not we will call upon Dr. Perrine for his paper.

AMERICAN PRACTICE IN HIGH-TENSION LINE CONSTRUCTION AND OPERATION.

BY DR. F. A. C. PERRINE, *Delegate of the National Electric Light Association and of the Pacific Coast Transmission Association.*

A characteristic of American practice is that it tends toward standards not only in the matter of the sizes of units, speeds and manufacture appearance, but also in the methods of producing results and in types of engineering. While it may be true that this tendency was originally based upon a desire for cheap manufacture and interchangeability of parts, at the same time it must be understood that the present elaboration of this policy is somewhat due to the fact that in so large a country the ideas of the best men cannot be directly applied except as they may be adopted for standards. No one section of the country produces the best men necessarily, nor does any one group of engineers dominate our practice. On the contrary, the meetings of our engineering societies have taken the character of sittings of committees, where are presented many plans, and where all plans are carefully discussed and sifted. From those presented the best is chosen and becomes the standard.

Accepting these results as the standard does not imply that there is general in this country a spirit of copying or of servile imitation among the engineers. On the contrary, we feel that the result of the attitude so prevalent in American engineering at the present time, of establishing standards, has introduced a wise spirit of conservatism, and has thrown the burden of proof upon each one presenting a new idea. At the same time it has resulted in raising the character of the average engineering work throughout the country, until today good American engineering can be found, not only in the great spectacular plants near enough to the large centers of progress to have the personal attention of the most experienced engineers, but in consequence of this system of practice an equally good type of engineering can be found in the plants in the out-of-the-way deserts or mountain regions, where

the local engineer of good capacity, knowing his conditions thoroughly, has relied upon the standards established by his fellows in those particulars where his own experience has been limited, and in consequence a plant is produced, not only more perfectly adapted to the particular circumstances of its surroundings, but in all details more thoroughly satisfactory than could have been designed under any other system. Our rule is that invariably one should adhere to well-established practice and introduce such modifications as are made necessary by the local conditions. This does not limit the full employment of the energies and brains of the local engineer, since, without a special consideration of outside details, there is always in every transmission plant particular circumstances which tax the ingenuity of the best. That this is the general method of American practice will be seen by any one who consults the report of the standardizing committee of the American Institute of Electrical Engineers. The report covers, not only units, standard methods of testing, and details of manufacture, but also procedure, both outdoor and in, for all types of plants, and this report in itself has resulted in a certain similarity of type where problems to be solved are similar.

The work of the transmission engineer lies in fields so essentially dissimilar that even in spite of this general tendency it may be difficult at first view to ascertain what is the American practice in work of this class. On closer examination one finds, however, this work falling into natural groups dependent on the length of transmission and the voltage employed, though what has been done has been materially modified by the date of erection, since during the past ten years modifications in the arts have been necessarily reflected in the types of construction.

The general groups have been somewhat decided by the manufacturers of machinery, who have presented as preferable certain available voltages. Above 2400 volts, where transmission proper really begins, the first voltage now commonly employed is 6600, which figure has been established as standard by the needs of the lighting plants in the great cities, and has been adopted by the transmission companies in place of either a higher or lower voltage mainly because it is a standard. For this voltage direct generation at high pressure is almost invariably used. The next higher voltage now commonly employed, and practically the first one for which step-up transformers are used, is 15,000. During the past few years this has taken the place of transmissions at

10,000, 12,000 and 13,000, and it is today the established voltage for high-tension electric railways, the general reason for its establishment as a standard being that this voltage is not more difficult to handle, as regards insulation or switching, than the three last-mentioned lower voltages, and, furthermore, that, where the lower voltages have been previously established, the sphere of operation of the transmission plant has been found to be rather too much limited. There are in the Rocky Mountain region and west a great number of the older plants operating at 10,000 volts, and whenever direct high-voltage generation has been attempted, voltages of from 12,000 to 13,000 volts are used; but, at the same time, the majority of the plants which have used these lower pressures in the past today have circuits with special transformers operating at the higher figure. The next step is to 25,000 volts, which is the highest figure reached without special study of insulators, switches and lightning arresters. This voltage has been successfully handled without serious trouble during the past six years. A voltage of 33,000 is employed in a number of plants built about five years ago, and at this figure the special difficulties due to line capacity, insulator size, erratic lightning-arrester effects and switching begin to make themselves seriously felt. Above 33,000 volts the standard voltage is called 60,000, although in all plants that have heretofore been established to operate at this pressure, there have been installed transformers arranged for connection to various voltages of from 40,000 up to 60,000 volts, and the majority of these plants are today operating at about 50,000 volts, some of them being unable to operate at the highest pressure on account of the character of line insulators originally installed. In the choice of voltage for any transmission it is considered the best practice to establish it at the rate of 1000 volts per mile, provided the length of transmission be not above 60 miles, since above 60,000 volts no commercial work has been regularly attempted. In the table recently presented by the transmission committee of the American Institute of Electrical Engineers, the highest average voltage per mile for any one class in their report is 840; but in examining this table it must be remembered that their correspondents have reported the total length of line in service, so that, if a plant be operating two lines fifteen miles each in length at 15,000 volts, the table would indicate an operation at 500 volts per mile, although for each line the transmission was at 1000 volts per mile.

The common lighting frequencies of 125 and 133 have, for transmission lines, given place entirely to the frequencies of 60–40–30 and 25, no use having been made in this country of the frequency of 100, and only in one locality has there been any employment of 50 periods.

In the transformation from one frequency to another, which is found often to be advantageous, simple apparatus would be employed if the frequencies in use were multiples of each other and use made of 25–50 and 100 or of 30–60 and 120, but, unfortunately, the four frequencies mentioned have been practically used and are to-day too thoroughly established for further change.

Systems in which lighting is the principle element, and where distribution over a wide territory make the work of small communities an important element to the business office, employ a frequency of 60 periods per second and at this frequency large amounts of energy is transmitted to considerable distances at the highest voltages. The frequency of 40 is largely confined to transmissions from which cotton mills are operated, this having resulted in motor speeds suitable to their line shafting.

For a number of years the two frequencies of 30 and 25 have contested for supremacy in plants primarily established for power purposes and for the operation of rotary converters, but largely on account of the very great amount of machinery installed at Niagara and employing a frequency of 25 that is becoming more and more to be the established standard for power purposes and seems likely to displace altogether the higher, which has no distinct superiority except that it is one-half the standard frequency used in lighting.

In the generation of power the revolving-armature machine has almost disappeared from the new plants, and revolving-field generators have become so settled in type that those produced by different manufacturers are hardly distinguishable by the casual observer. For the low-head plants using turbine wheels it is necessary to provide for a 50 per cent increase of speed, and in the high-head plants, where impulse wheels are employed, a strength sufficient to withstand a speed increase of 100 per cent must be allowed to provide against damage from overspeeding should the power be thrown off and the water continue to flow. The machine fulfilling these conditions and practically adopted by all the manufacturers is characteristically a revolving field machine with the poles keyed to a cast-steel spider, the field windings being of copper strip wound upon edge, the armature

being constructed of a cast-iron box girder supporting the stationary armature laminations. Almost the only departure from this type of construction for power-transmission work is found in the balanced type of inductor machine, where the field is magnetized by a central stationary field coil wound with copper strip, the armature in two halves symmetrically arranged around the central core being of laminations supported either by cast-iron rings connected together by cold-rolled steel bars or supported by a steel shell to which the armature laminations are keyed.

Various station voltages have been employed, but, where direct generation at 6600 or 12,000 volts has not been resorted to, the practice is setting more and more to the use of about 2300 volts, this being chosen because the lower voltages require large extra station copper and the higher voltages are felt to introduce unnecessary station difficulties of insulation and switching. For switching, the present type of 2300-volt oil switch has been so well developed, by reason of the great number of plants operating at this pressure, that for handling a particular amount of energy it is both cheaper and better than any 500-volt switch on the market.

For plants operating at less than 25,000 volts, the step-up transformers in use are about equally divided between the water-cooled, oil-filled types and air-blast types. Where a good supply of water is to be readily obtained, the oil-filled transformers have generally been given preference, as they can be more readily adjusted for a varying flow of water at different loads. The question of the relative fire risk from the two types has been extensively discussed, and it can hardly be said that any very definite conclusion has been finally reached, though the weight of opinion seems by far to be that the fire risk is at least not increased by the use of the oil-filled transformer, and the actual risk in either type seems to be a matter largely of installation. It is perfectly true that there have been some very serious fires, resulting in the complete destruction of power plants, where oil-filled transformers have been used, but in each case the fire has started outside of the transformers, though they themselves, by reason of being installed without reference to safety in case of fire, have furnished fuel which has augmented the conflagration. Today the conditions of installation for safety are better understood, and it now only remains to be decided whether, in the case of a fire actually arising, the oil shall be run out and the transformer cases filled

with water, or the whole transformer protected, either by running an excessive amount of water through their cooling coils, or by so installing them that the transformers may temporarily be submerged to within a few inches of their tops. Actual protection of transformers by running water through their cooling coils has been found to be effective in at least one serious fire.

For high-tension switching, use has been made of a long arc broken between carbon terminals, long-inclosed fuse, a fuse drawn through a tube filled with a fine, non-conducting powder, and of oil switches. The first two types, while interrupting the circuit well, draw an arc of excessive length and produce a surging which may result in an increased potential of at least as much as 50 per cent. In consequence, these types are rapidly disappearing except in plants operating at 15,000 volts and below, where the carbon break is preferred to the inclosed fuse, though it is common to install the two in series, allowing the fuse to operate as a safety device, but not for the purpose of switching. The type of switch where a wire is drawn through a tube filled with powder is found to operate successfully up to 40,000 volts and without serious surging on the circuit, but the powder being blown out with great force, scatters over the entire station, and is in consequence not allowable. The oil switches mainly employed are those with the vertical break and those with the horizontal break. The vertical-break switch has the advantage that the amount of oil contained in the oil-tank is relatively small, and will add to possible conflagration only a slight amount of fuel. This switch is found on severe short-circuits often to blow all the oil out of the tank unless the tank is built very strongly, when it becomes necessary to insulate the plunger from the tank as it enters the switch. The horizontal-break switch, while containing a large amount of oil, will for the same length of break, handle about 25 per cent more energy at any definite potential. This switch can successfully be used at 60,000 volts, and up to the present time has not been found to blow the oil from the tank. These two types of oil-switch are the standard today, no distinct preference being given to the horizontal switch, though the writer believes that in the future this type will be used as a standard for the highest potentials.

Transmission with two-phase connection of circuits, whether using three or four wires, has for voltages above 6600 given place entirely to transmission with a three-phase connection,

though three-phase transmission with two-phase distribution described by Mr. Scott at the International Congress of 1893 is very extensively employed.

The relative merits of the delta and star connection of the lines to the transformers is still somewhat in dispute, so much so that in plants of the highest voltage, where several voltages are provided, certain of the lower voltages are obtained by delta connections to the transformers, while the higher voltages are to be obtained by a star connection. In general it may be stated that up to 25,000 volts the delta connection is generally preferred, principally because with this connection a ground upon one line does not necessarily result in a short-circuit, and, furthermore, the service is not necessarily interrupted in the case of the failure of a single transformer. At voltages higher than 25,000 volts the transformers for delta connection become more difficult to build and insulate. Furthermore, a single ground anywhere produces disturbances of a serious character, and in consequence the star connection with the grounded neutral is employed, advantage being taken of the fact that a grounded neutral aids in the distribution of unbalanced loads, and furthermore the rise of pressure which may occur from line discharge at the time of an open-circuit or a short-circuit are not so likely to produce serious results.

For the distribution of current through the low-tension mains, it is generally the custom to transform to 2300 volts two-phase unless either the load is mainly one of motors, or unless there are important motors of considerable size to be supplied at a distance of half a mile or more from the sub-station. In such cases three-phase star-connected four-wire distribution is employed, allowing the connection of distributing devices either to a 2300-volt circuit between lines and the neutral wire, or a connection to a 4000-volt delta circuit for balanced loads. This combination of circuits is found to be extremely useful where a mixed load is to be supplied at varying distances.

The high-tension lines themselves are preferably run over private right of way. Railroad rights of way were at first highly prized on account of the entire absence of trees and disturbing structures, and furthermore on account of the fact that inspection and repairs are most easily provided for; but experience with such lines has proven that, for transmissions at even so low a tension as 15,000 volts, the interference with insulation by the smoke from the locomotives, which covers the insulators, more than

counterbalances all the advantages, and today such rights of way are more commonly shunned than sought. Where railroad locomotive smoke combined with sea fog is encountered, it becomes absolutely necessary to clean each insulator at frequent periods, even though the voltage of transmission be not more than 5000 or 10,000. Along the country road this difficulty is not apparent, but in some localities farm structures and trees interfere with the transmission, so that in general it may be said that a private right of way that the transmission company can absolutely control is much to be preferred.

In the most recent types of construction the height of pole is limited as much as possible. While there may be some increased security from malicious disturbance in the use of high poles and a decrease of line capacity may be expected, these advantages are only obtained at the expense of stability and at an increased cost. A pole 35 ft. long set 5 ft. in the ground permits the safe installation of either a single three-phase line with a spread of as much as 6 ft. by supporting one insulator on the top of the pole and the other two on the ends of a long cross-arm; or it may be used to support two three-phase circuits on opposite sides of the pole with a spread between wires of 3 ft. by the use of two cross-arms, and at the same time such a pole permits the safe installation of telephone or other signaling circuits on brackets or cross-arms at a safe distance below the power lines. These poles should not be less than 8 in. in diameter at the top and not less than 12 in. in diameter at the ground line. Variations from these dimensions may be considered as being due to special considerations based upon the location of the lines or arrangement of the circuits. It is true that such a standard pole may only be arrived at after a consideration of the wind stresses on the particular lines taken in conjunction with the spacing of the poles, but as the maximum pole spacing on transmission lines is about 135 ft., at average wind velocities these pole dimensions may be considered safe. Extra strength required by variations of wind stress, either due to an increase in the number of wires or to a necessity for allowance for sleet, is more commonly taken care of by shortening the spans than by an increase in the size of the pole. In some cases where severe sleet conditions are to be encountered and the wires are large, it is the practice to install these poles at not more than 50 ft. apart.

The material used for poles depends largely on the locality.

In the Southeastern States chestnut is the favorite wood; along the Canadian border and through the Rocky Mountain regions cedar is employed, while square-sawn redwood is used almost exclusively on the Pacific Coast. With increase in voltages and consequent increased trouble from insulators, a demand has arisen for a pole-line construction which will permit a decrease in the number of insulators and allow an increase in the size of each. This has been accomplished by the use of galvanized-iron towers not less than 40 ft. from the ground-line to the wires, and spaced about 500 ft. apart. One plant in Mexico has recently successfully installed this method of construction. A second in the same country has contracted for its material, and a number of plants in the United States are contemplating its use. The question of the life of wooden poles depends not only upon the character of the wood and its condition when cut, but also upon the local conditions of atmosphere and soil. In some places the poles which are available have no longer life than about five years, and, in the extreme, wooden poles cannot be greatly depended upon for a period greater than 15 years, though the redwood poles installed along the lines of the transcontinental railroads west of the Rocky Mountains have in many instances given a life up to 35 years, and are still said to be in good condition; but these poles are set into a soil strongly impregnated with alkali in a country where rains are few and the air generally dry. Nothing is known as yet of the life of the galvanized-iron tower except from windmill practice, where towers which have been galvanized after all punching and machining is done are found to be in good condition after a period of 10 to 15 years.

The cross-arms in use are almost invariably made of pine without treatment other than painting. These arms are let into the pole from 1 to 2 in., being held by bolts through the pole and arm, and when long are additionally supported by braces. Even with steel poles wooden arms are used, the general feeling being that there is less probability of the circuit being completely disabled should an insulator break and the line fall, if it falls upon a wooden rather than a steel arm. At the same time an experiment in the use of wooden braces has not been found to result in any certain advantage. In consequence, flat galvanized-iron braces established a number of years ago as standard by the telegraph and telephone companies are now almost universally employed in the construction of transmission lines. With increase in spans and

voltages the insulators are increasing in size. This condition will probably in the future demand a strength of arm greater than can be obtained by the use of wood. This problem, however, has not as yet obtained a definite solution.

For plants operating below 25,000 volts much use has been made of glass as a material for insulators. Glass has been for many years the standard insulator material in American telegraph and telephone practice, and in spite of many experiments that have been tried with porcelain, it is still considered the best and cheapest material for this service. However, in transmission work one of the great advantages claimed for glass in telephone and telegraph practice disappears. The engineers of these companies claim that it is important to provide against dark, narrow spaces within the insulators on account of the fact that they form the homes of insects. The transparency of the glass largely obviates this difficulty. Where large insulators are used such as are employed by transmission companies, the spaces within the insulators are well lighted from below, and the transparency of the material is not important. Glass is comparatively fragile, and for transmission work it has nothing to recommend it except low first cost and cheap inspection; these, to be sure, are very often overpowering advantages when the voltage is low enough for the particular form of insulator used to provide a large factor of safety, and in consequence up to 15,000 volts glass insulators are generally preferred unless there are special climatic conditions which render them liable to fracture. Many series of tests have shown conclusively that the porcelain insulator has a greater mechanical strength, is less liable to surface leakage, has a safe dielectric strength, and in addition that it is exceedingly difficult to break the head of a porcelain insulator so as to allow the wire to fall away from it. The one disadvantage of porcelain is that there is an uncertainty as to its solidity, and that it is only possible to ascertain its solidity by most careful high-voltage tests. The question of the form of high-voltage insulator as yet is in high dispute, operating engineers being inclined to a design where the petticoats are very long and comparatively close together, so that great creeping distance be given over the surface of the insulator between line and line and between line and pin, comparatively little importance being placed on the flashing distance. Engineers of the manufacturing companies, however, incline toward one of a much more open type of large diameter and with few petticoats.

This latter form undoubtedly gives the greatest sparking distance, has the least dark spaces within it, and is more readily cleaned by rain storms. It is also important that such an insulator may be constructed to operate at high voltage without noise, and, as there is a definite loss of energy whenever the insulators on a line are noisy, it may be safely predicted that the open type of insulator is to be the one that will be in the future considered as the standard.

While, for a particular voltage, insulator size may be largely determined by the form, at the same time we may in general note that up to 10,000 volts insulators, whether of glass or porcelain, have a minimum diameter of about 5 ins. A 7-in. insulator can successfully be used on voltages as high as 25,000, a 13-in. insulator is sufficient up to 40,000 volts, while at 60,000 volts it does not seem safe to install insulators having less diameter at the top than 14 ins. A greater size would unquestionably invariably be used for these high voltages if the problems of the manufacture of porcelain and support of the insulator were altogether solved.

Insulators above eight inches in diameter are generally manufactured in several parts and either glazed together in the porcelain kiln or cemented together in the field. This method of construction allows a more thorough inspection of the constituent parts for solidity of material and also reduces the loss from breakage in transit. It has the disadvantage of introducing into the insulator a variable dielectric which, however, in line insulators has not been proven to be a disadvantage.

Attempts have been made to construct an insulator of two materials, such as glass and porcelain, but all such attempts have been now abandoned and the separable insulator is now constructed entirely of porcelain united with Portland cement.

In supporting the insulators on cross-arms it is necessary to provide that the lowest petticoat be raised above the cross-arm as much as the radius of the insulator, and, as the strain comes on the extreme top of the pin, it is obviously difficult to successfully support the largest size of insulators by means of the common pin and cross-arm construction. By using carefully selected woods, this has been successfully accomplished for insulators up to 11 ins. in diameter, but at 40,000 volts in bad weather such insulators carry enough current over their surface to char a wooden pin. Accordingly practice has settled to the use of iron pins in plants operating above 25,000 volts. At this voltage and below, the wooden pin can be

successfully used and indeed forms a certain protection to the line by reason of the fact that the pin itself is a semi-insulator, and is only in danger of being burned when the insulator is punctured. Above this voltage, however, only metal pins can be employed, not only on account of the large size of the insulator, but also on account of the fact that there is much burning of wooden pins. The manner in which these pins are burned has attracted considerable attention, having presented some problems which are exceedingly interesting. There is no doubt but that the effect is due to leakage over the surface of the insulator, but it is extremely interesting to note that in some cases the pin is actually charred, whereas in other cases there is an apparent dis-association of something in the wood, and peculiar salts are left behind either reduced from the atmosphere or from the material of the wood itself. This matter was discussed by Mr. C. C. Chesney in a paper read before the American Institute of Electrical Engineers.

The materials that may be used for wooden pins are locust and eucalyptus. The latter wood is decidedly preferred in the plants west of the Rocky Mountain region and where it is readily available, as the wood has been found to be as strong as hickory, dense, and readily handled when thoroughly seasoned and dried. For the largest sized pins, however, as has already been said, no wood is entirely satisfactory, and in consequence use is made of malleable cast-iron or cast-steel.

As regards conducting material, it may, of course, be said that the only materials at present available are copper and aluminum. For a number of years there has been a discussion of the possible use of iron for short lines on high-potential plants, since the smallest copper wire that may successfully be strung is unnecessarily large under such circumstances. This procedure, however, has not obtained the approval of any of our electrical engineers. The copper wire is invariably uninsulated in high-tension work, since it is correctly believed that no insulation is a true protection, and the frank nakedness of the bare wire is a warning, and in consequence a safeguard to those who are compelled to work near the line.

Copper is used either soft, hard-drawn or stranded. For transmission work, where the wires are smaller than 0.3 in. in diameter, use is not made of soft-drawn wire, and it may be stated that the

standard in American practice is to use soft-drawn wire only for large, low-potential circuits where the small change in conductivity due to the hard drawing is an important factor. Up to 0.3 in. hard-drawn copper may be considered standard. Between 0.3 in. and 0.4 in. diameter the practice is evenly divided between solid hard-drawn wire and strand. Larger than 0.4 in., strand is almost invariably employed. Some use has been made of solid aluminum, but, as the material must be handled with great care, it has been found generally to be the better practice to employ aluminum strand, which is more readily installed and more reliable after being installed.

Preference between aluminum and copper is almost entirely a matter of price for transmission lines. It is true that aluminum is stronger in reference to its weight for the same conductivities than copper, but at the same time it is materially larger, and the resultant transverse wind stress on the line greater. For short lines, delivering a small amount of power at voltages of 40,000 or above, aluminum is decidedly to be preferred, since it is found that at these voltages a wire less than 1/4 in. in diameter will discharge through the air, and this discharge may result in a considerable loss of energy. Accordingly, it is not possible at these voltages to successfully use wires less than 0.3 in. in diameter, no matter what the amount of energy or the distance. Accordingly where the amount of energy and the distance may result in the loss not being the determining factor, aluminum is much preferable for the reason that at a definite size it is materially cheaper than copper. Where salt-sea fog is to be encountered, both aluminum and copper are acted upon. The action on aluminum is greater than the action on copper, and in consequence copper must necessarily be used. Where such conditions are not encountered, aluminum is an entirely safe material provided it is not exposed to the elements in contact with any other metal. The joints, therefore, must either be made of aluminum of the same quality as the wire, or the joints must be carefully insulated so that no moisture will penetrate. Aluminum must be strung with careful reference to the temperature at the time of erection, since its coefficient of expansion is very large, about three times the coefficient for copper, and experience in the erection of copper lines will result in an unsafe aluminum line. Careful tables have been prepared as to temperature, span and sag, and, when these tables are

followed, no apprehension need be felt as to the safety of the line.

The most difficult problem at present encountered in the construction of high-tension transmission lines is that presented by the lightning arresters. For voltages up to 25,000, the non-arcing types of lightning arresters, either with or without series resistances, may be successfully used. Above this voltage and where large amounts of energy are available, these arresters are found to be short-lived, and up to the present time no thoroughly satisfactory arrester has been presented, which does not, when interrupting the ground circuit after a discharge, injure the insulation of the line and transformers. The horn form of lightning arrester developed in Germany has been found to operate with invariable success so far as the lightning arrester itself is concerned, but, as it is interrupting the ground circuit, it draws a large arc, and oscillations are produced on the line, which in many cases have been found to have more serious results than the discharge they were installed to remove. Condensers in parallel with the lightning arresters and ingenious arrangements of condensers and resistances have been used with some success, but none of these plans may be considered to be entirely satisfactory for the highest potentials operated from the largest generating plants.

In the operation of such lines every effort is made toward maintaining continuity of service. Such lines are carefully patrolled, even when it becomes necessary to build a special runway for the patrolman, and it is remarkable with what certainty these experienced men can predict the hours of life of a failing insulator, and provide for voluntary interruption of the service in time to remove the imperfection. Duplicate lines for long-distance work is an invariable necessity, though by far the best protection that can be offered for service is the supply of current from different power stations over lines following different routes. The present tendency is toward the consolidation of plants, not only for the purpose of decreasing the general operating expense, but more particularly for providing continuity in the case of the most serious accidents. No difficulty is experienced in operating in parallel plants widely separated, and where a number of plants are feeding into the same network, to certain plants are assigned the regulation of the entire system, others feeding the circuit being allowed to operate their machinery at full load continuously. The line capacity offers the most serious problem in determining regulation where the loads vary widely, but this quality becomes important

only for great variations of load, which, as the plants increase in size and load, are disappearing. Where proper care has been given to the installations of the lines and where duplicate lines and plants are provided for, care in operation and patrol of the lines has resulted in success both from the engineering and financial standpoint.

There being no discussion upon the paper, the Section voted an adjournment to Thursday morning.

THURSDAY MORNING SESSION, SEPTEMBER 15, 1905.

Dr. Louis Bell called the Section to order.

SECRETARY BELL: In the absence of Mr. Scott, the chairman, who was suddenly called away, we will do well to start the work of the Section now as early as possible, and the first paper before us is that upon sparking distances, by Mr. H. W. Fisher. The question of sparking distances is one which Mr. Scott and myself believe to be rather more pertinent to our Section than the one in which the paper was originally placed, so we have borrowed or stolen Mr. Fisher, who will now kindly read his paper on sparking distances.

SPARK DISTANCES CORRESPONDING TO DIFFERENT VOLTAGES.

BY H. W. FISHER.

Realizing the advisability of using sparking distances for determining impulsive rises of voltage, the writer commenced a series of experiments about the beginning of the last decade with a view to learning how the sparking distances varied with the voltage and the kind of points. The results obtained then showed that the subject was very complex and that the problem could only be successfully solved by using a great variety of points whose diameters had been carefully measured. Such work the writer undertook and accomplished sufficiently well for his own use. It was his intention, however, to go more fully into the subject and present his researches in the form of a paper. About that time Mr. Steinmetz read his excellent paper entitled "Dielectric Strength of Air" before the American Institute of Electrical Engineers.

After the adoption of the table giving the sparking distances corresponding to different voltages by the American Institute of Electrical Engineers, there has been a tendency to use this table for measurements of high voltage, and in the present paper it is the object of the writer to show the magnitude of the errors that may arise from the use of ordinary needle points.

For these investigations, current from 2,000-volt, 60-cycle generators was furnished by the Allegheny County Light Company. Through the kindness of Mr. W. A. P. Schorman of said company, the voltage and frequency were kept very constant, and while making individual tests the voltage seldom varied more than 1/10 per cent. Considering that our line was taken off of one of the regular lighting circuits this result can be considered remarkable, and such constancy was, of course, invaluable in our investigations.

The apparatus consisted of a water resistance placed in series with an auto-regulating transformer, and the lighting circuit. From the secondary of the auto-transformer, current was supplied to a large high-voltage transformer. By means of the regulator,

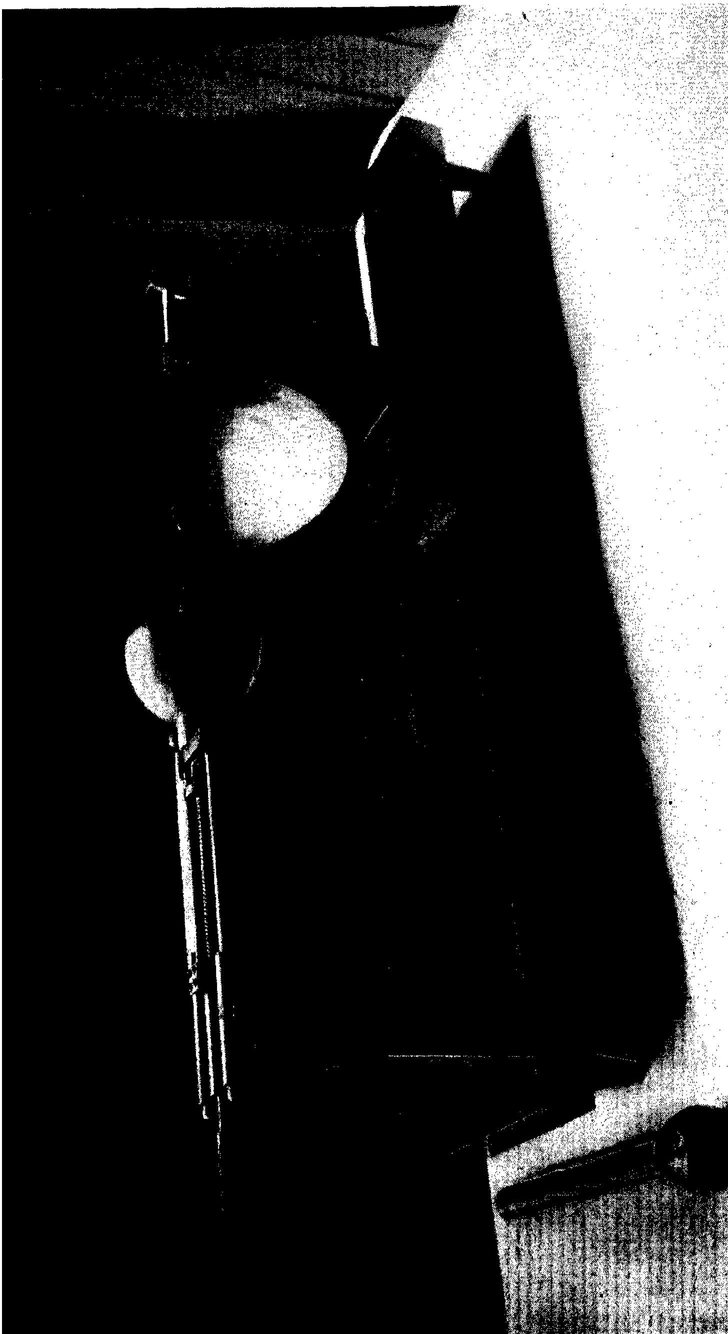


FIG. 1. SPARK-GAP APPARATUS.

the high voltage could be varied by steps of 1 per cent, and the water resistance could be changed so as to give absolutely any voltage desired. The high voltage was measured by means of a Weston voltmeter placed in series with non-inductive resistances. The Weston voltmeter was very carefully calibrated by a potentiometer method, and its impedance, as well as those of the resistances used in series with it, were measured and the multiplying factors of the different resistances were calculated.

After all this preliminary work was done voltages could be measured to an accuracy of nearly 1/10 per cent.

Fig. 1 shows the spark-measuring apparatus, which consisted of a heavy base of hard rubber on which was mounted rigidly one needle-holder screw and micrometer, reading to .001″. The other needle-holder could be moved forward or backward in a groove and fastened in any desired position to suit the length of needles employed. The actual needle-holders were provided with ball-and-socket joints so that the points of the needles could be placed exactly opposite each other. Concave discs of different diameters could be placed slightly back of the needle points as shown in the cut, where for the purpose of illustration and comparison a 4″ and a 10″ disc are placed over the holders. The writer found that by the use of said discs, the sparking distances were more uniform. The discs reduce the amount of brush discharges, which without them sometimes suddenly become sufficiently great to start a spark before the right distance is reached. The hard rubber handle is placed to the left of the apparatus. They do not prevent abnormal spark distances due to impulsive rises of voltage. Other advantages of their use will be mentioned later on. The apparatus was designed by the writer and made by The Leeds & Northrup Company of Philadelphia, Pa.

As the e.m.f. wave form of an alternating-current generator changes with the amount and kind of load, it was decided to make a few spark distance measurements at a definite voltage every time any tests were made, and to confine the experiments mostly to times of the day when the generator load would be fairly constant. The definite voltage referred to above was 25,240, which corresponded to a voltmeter reading of 83.5, the voltmeter multiplier being 302.4.

In order to always get a deflection of exactly 83.5 it was necessary to use a water resistance, and hence as a water resistance in the primary of a transformer has a tendency to change the relation

between maximum and mean effective pressure of the secondary voltage, it was necessary to determine through what range the water resistance could be operated without affecting the e.m.f. curve.

Table I gives the result of this investigation, and it will be seen that when the water resistance was set at 20, the change only amounted to 1/10 per cent. Therefore, throughout the tests, we never reached this point, and the settings were mostly between 10

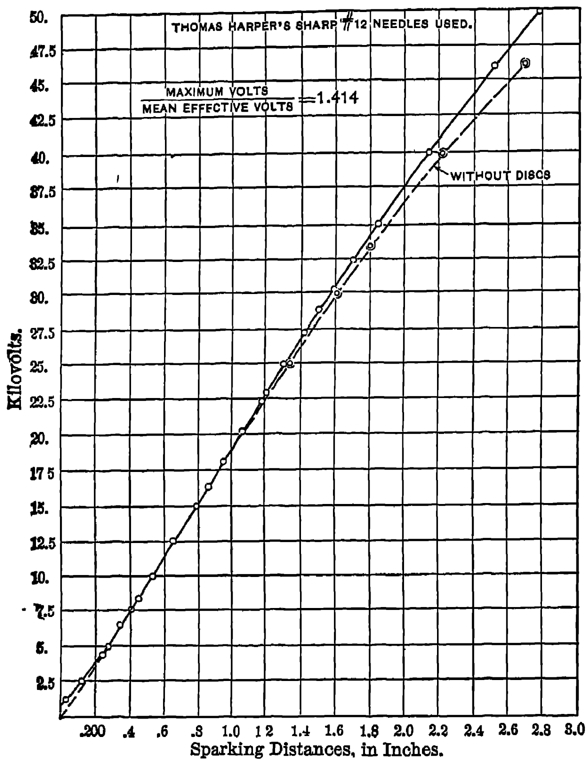


FIG. 3. SPARKING DISTANCES CORRESPONDING TO MEAN EFFECTIVE A. C. VOLTAGES.

and 15. It will be interesting to note that the maximum water resistance made an increase of 4 per cent in the spark distance.

From work done years ago, it was found that more consistent results could be obtained by the use of sharp points, so No. 12 Thomas Harper's "Pro Bono" needles were employed in these investigations.

It was decided first to determine accurately the spark distances

corresponding to different mean effective e.m.f. In doing this work, a great many tests were made at different voltages, and in each instance a reference spark distance at 25,240 volts was obtained. Ten-inch discs were used and each was placed $\frac{1}{2}''$ back of the needle points. The zero micrometer reading was determined by inserting a piece of mica of known thickness between the points and advancing one of them till the mica touched both.

Through the kindness of the Westinghouse Electric & Manufacturing Company the writer measured the spark distance correspond-

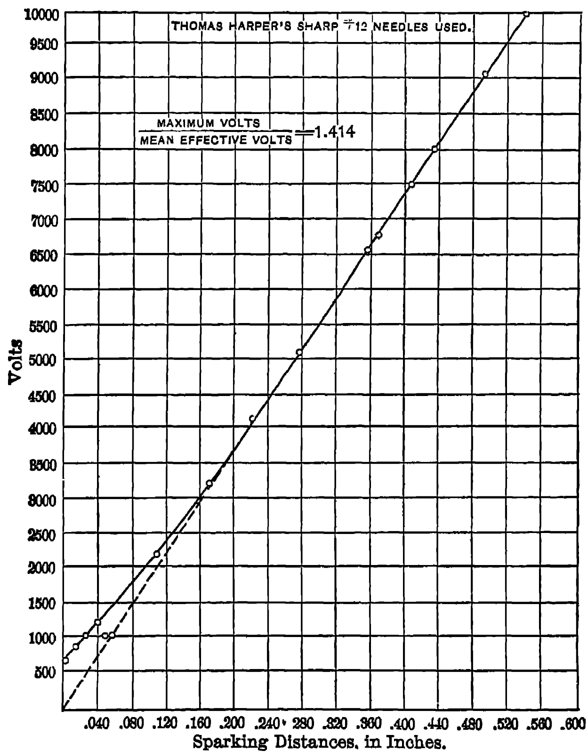


FIG. 4. SPARKING DISTANCES CORRESPONDING TO MEAN EFFECTIVE A. C. VOLTAGES.

ing to 25,000 volts mean effective pressure, which was obtained from an unloaded transformer and generator whose e.m.f. curve was accurately known. The ratio of mean effective pressure to maximum pressure of this generator was .705, which is remarkably close to that of a curve of sines, viz., .707.

From all of these data, it was found that the spark distances for 25,000 volts mean effective pressure of sine curve should be 1.300″. It then became a simple matter to correct all the measurements obtained to the basis of a curve of sines and the curves of Figs. 1 and 2 represent said connected results.

The curve of Fig. 3 gives the result of tests made with No. 12 Thomas Harper's needles. The main curve going up to 50,000 volts was made with the use of 10″ discs. The subsidiary curve was obtained from tests made without the use of discs. Below 23,000 volts there is apparently no difference between tests made with and without discs. The discs seem to have a tendency to make the curve more nearly a straight line. The utmost care was taken with this work, and unless the form of the apparatus and surrounding conditions have an effect upon sparking distances, the writer believes the results herewith given are very accurate. The relative results at all events should agree very closely, and if at any time it should be found that the correct sparking distance for 25,000 volts be greater or less than 1.3″, the values given by this curve can be modified to a proportionately greater or less degree.

The curve of Fig. 4 is made on a larger scale and with assorted needle points, none of which were blunt. By doing this, there were not many tests to be eliminated. The curve is practically a straight line through the upper range of voltages. Mention will be made later of the dotted line which becomes tangent to the curve and passes through the origin.

Table II gives a comparison between spark distances tests made with and without 10″ discs. It will be noticed that the spark distances were more uniform with the use of discs than without them. A great many similar tests were made, all of which confirmed this point.

In most of the following tables, the measured diameter of the needle points is given. The points were measured by means of a microscope and glass grating containing 10,000 lines to the inch. The kind of points were classified into flat, round, and sharp, which are designated respectively by the letters *F*, *R*, and *S*. Each point was measured in two directions 90 deg. apart. Under the column headed "Kind of Points," will be found the measured diameters of both needle points used in the test. It will be noticed that many of the points were both round and flat, depending upon the direction in which they were observed. The "Distance between Discs" is the actual distance between them when the needle points

were touching, and each disc was placed half this distance back of the points.

Table III gives some very interesting tests made with 1000 volts, a great variety of diameters of points being employed. With this voltage it is at once evident that the sharper the point the longer becomes the sparking distance. It will be noticed that the sharpest needle point gave a spark distance equal .041″, while with electrolytically prepared points spark distances of .048″ and .052″ were observed. On one occasion the writer made points which appeared still sharp under a magnifying power of 600 diameters, and with these points the spark distance was .054″.

Referring now to Fig. 4 it will be observed that a straight line drawn tangent to the spark distance curve and passing through the origin intersects the 1000-volt line at .054″. It is the writer's opinion that this straight line would represent the spark distance curve if infinitely sharp points were employed; other tests and curves which the writer obtained many years ago all tend to confirm this opinion. With polished pin heads the sparking distance was as low as .0025″. The points of large diameters were made by rubbing the ends of the needles across a fine carborundum stone. It will moreover be noted that the sparking distance is controlled by the sharp point and not by the blunt one.

Table IV gives a great variety of experiments made with about 6200 volts. Section A of this table gives tests made with points of various diameters. A glance here will show at once that a maximum spark distance is no longer produced by sharp points, but by points which have a diameter approximating .0014″; this rather startling fact the writer discovered over 10 years ago, but did not then have the means of determining the diameter of the point which gives the maximum spark distance. The same results are in general true without the use of discs, but, of course, it may be possible that the diameter of points giving a maximum spark distance is different when discs are not employed.

The writer next tried to determine whether the blunt or sharp point was the controlling factor in determining the sparking distance. In doing this the astonishing fact was discovered that the sparking distances were always greatest when the large point was placed in the holder at the handle side of the apparatus when 10″ discs were employed. When no discs were employed the exact reverse of the above occurred, the spark distance being the greatest when the small points were at the handle side of the apparatus.

Section C of Table IV shows that when 4″ discs were employed the position of the small or large point had no effect upon the result, the sparking distance varying with the diameter of the point and being practically the same as what was obtained before, when blunt points of the same diameters were used. The 10″ discs were not symmetrical, having been considerably warped in transportation, whereas the 4″ discs were very symmetrical. Whether this was the cause of the peculiar phenomenon or whether it was due to the diameter of the discs, the writer did not have time to discover. It will be noted in section B that when 10″ discs were employed the sparking distance depended entirely upon the kind of point which was placed at the handle side of the apparatus, whereas, when no discs were employed, the kind of point at the other side of the apparatus was the controlling factor.

Section D of this table gives tests made with different sides of the apparatus grounded, and the results were so uniform that for all practical purposes the grounding of either side of the circuit does not affect the sparking distance.

Section E shows tests which were made with a view to determining whether different diameters of discs had any effect upon the sparking distance. Considering that all these tests were made with current obtained from an ordinary lighting circuit, these results can be considered close enough to indicate that the size of the discs does not have any practical effect when 6000 volts are employed. This table shows us that by the use of points having a diameter of about .0014″, the spark distance can be increased over 20 per cent more than what will be obtained by the use of sharp points. The measurement of several packages of needles shows that nearly every package had needles which measured as much or more than the above. Hence, while several tests would probably give quite close results, yet one or two tests cannot thoroughly be relied upon to give the correct sparking distance.

Table V gives the result of a number of tests made with 10,100 volts. Section A gives the tests which were made to determine the diameter of the point which would give the longest spark distance, and from careful examination it will appear that the maximum distance is obtained from points measuring about .0018″. The distance does not seem always to depend upon the diameter of the points, because the seventh line of figures shows a comparatively small distance compared with the twelfth line,

where the points measured about the same. In the latter case, however, the points were round, and this may have been the cause of the difference. Here the maximum sparking distance is about 20 per cent greater than the minimum, and by making only one or two tests at this voltage without the use of measured points, an error of 10 or 20 per cent might have occurred.

Section B shows that when a large point is used on the handle side and a small point on the other side, that the spark distance is slightly greater than when the reverse is true. The difference, however, is not nearly so great as was the case when 6,000 volts were employed.

Section C verifies the tests made at 6,000 volts, namely, that when 4″ discs were employed, the position of the large or small points in the holders does not have any effect on the results. The sparking distances for sections B and C do not seem to be quite so great for large points as was the case in section A, where both large points were used.

In section D no discs were used, and when the small point was on the handle side of the apparatus, maximum results were obtained which corresponded quite closely to those in section A. When the large points were on the handle side of the apparatus, the sparking distance is considerably less, and this corresponds with the results obtained with 6000 volts with this exception, that the difference is not quite so great.

Section E shows tests made with different sides of the circuit grounded, and the connection to earth does not appear to change the sparking distance. A close examination of section A will show that the sparking distances are proportionately longer for rounded points than for flat points of the same diameter.

Table VI gives a number of spark distance determinations made with 20,000 volts. Section A of the table gives a series of tests to determine the effect of points of different diameters. It will at once become apparent that at this voltage the spark distance varies but little with the diameter of the points. The maximum spark distance was obtained with points measuring .003″, and was only about 3 per cent greater than the spark distance with sharp points.

Section B shows that when blunt and sharp points are used, the position of the point in the apparatus makes but little difference in the sparking distance. It will also be seen that at this voltage

the grounding of either side of the circuit does not affect the sparking distance.

Section C shows that when no discs are employed, the sparking distance is slightly increased by grounding the handle side of the apparatus.

The first test of section D shows that the sparking distance was about 0.005″ greater with discs than without them. The rest of section D demonstrates that when 4″ discs are used, and when different sides of the apparatus are grounded, the spark distances are probably slightly greater than those made with the apparatus not connected to earth. The results are apparently not so regular as those obtained by the use of 10″ discs. Experiments demonstrated the fact that with high voltages better results were obtained by the use of large discs.

Table VII gives a number of tests made with 30,200 volts. In sections A and B will be found a comparison between spark distance tests made with and without the use of discs. The results were much more uniform when discs were employed, and the average spark distance is about .020″ greater in section D where no discs were used than in section A where 10″ discs were employed.

Section C gives the result of tests made to determine the effect of points of different diameters upon the sparking distance. A careful examination will show that there is nothing at all regular in this part of the table. The blunt points seem to be instrumental in starting discharges which were followed by an actual spark. In many cases there appeared to be a kind of resonant action. When the heterogeneous results given in section C are compared with the tests of A and B, the importance of using sharp points becomes very apparent. Of course, in many cases when number 12 needles were employed, the spark distances were abnormal, due either to an impulsive rise of voltage, or to the needle points being blunt. Such irregular results are not given.

Table VIII gives the result of experiments made with 40,000 volts. In section A an attempt was made to determine the effect of placing the discs at different distances apart, and as mentioned heretofore, the distances given are those at which the discs were separated when the needle points were touching. The sparking distance seems to be slightly increased as the distance between the discs is increased, but the probable difference is small.

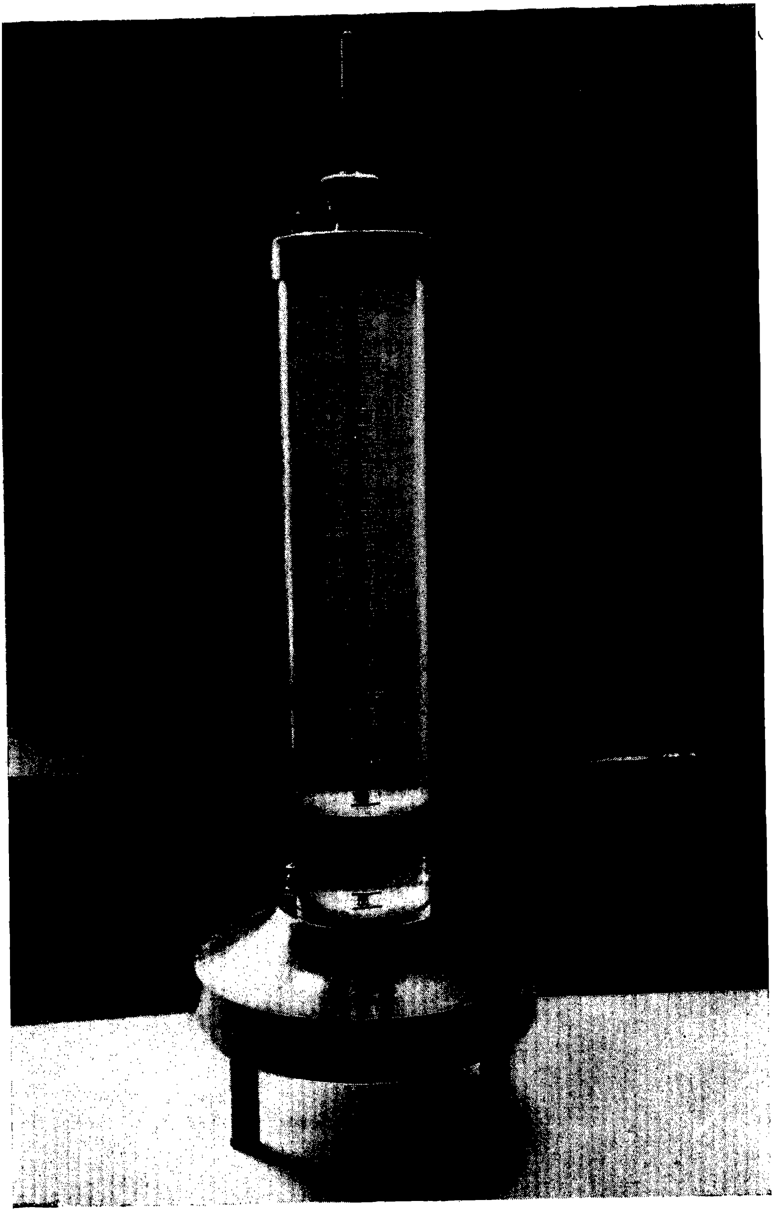


FIG. 2. LIQUID RHEOSTAT.

Section B shows that the sparking distance was about .1″ greater when no discs were used than was the case with 10″ discs separated by a distance of 1½″.

Section C shows that when blunt points are employed the sparking distances may vary through very wide limits. In both sections C and D the results are so irregular that no attempt at classification could be made. A number of other tests were made along this same line with similar results.

Section E illustrates the effect of grounding either side of the circuit. The results here are so irregular that it is impossible to tell whether a ground increases or decreases the sparking distances. This irregularity may be partly brought about by static discharges in the transformer. A great deal of time was spent in making tests at the higher voltages, and the results obtained were often very confusing, but the absolute necessity of using very sharp points was thoroughly demonstrated. About 2,000 needles were used in these experiments.

The e.m.f. wave curve of the generator furnishing current for these tests was probably very close to that of a curve of sines. On some occasions the sparking distance for 25,000 volts was 1.300″, but generally it was slightly in excess of this.

Table IX gives a comparison between the sparking distances of the A. I. E. E. table, and those of the writer. Both show an exact agreement at 25,000 volts; above this point the institute distances are greater and below they are less. It is an interesting fact that the tables agree at 25,000 volts, which was the reference voltage used by the writer. The institute sparking distance table was based on Mr. Steinmetz's researches, and if he used large needle points in his investigations, his sparking distances above 25,000 volts should be greater than those of the writer; this may be the cause of the difference there, but it does not account for the shorter distances below 30,000 volts. At 45,000 volts the difference between the institute sparking distance and that of the writer is about 14 per cent, which means a difference of over 5,000 volts. In the case of voltage tests where the sparking distance is relied upon as an indicator of the voltage, this difference might become a very serious matter.

In order to prevent short-circuits when spark distance tests are being made, the writer designed the water resistance shown in Fig. 2, which is placed in series with the spark distance apparatus.

This apparatus was not used in these particular investigations. The tube is of glass, 4″ diameter of hole and 20″ long. It is filled with distilled water and has a resistance of about 25,000 ohms when the plunger is at the top. The plunger rod can be clamped in any desired position by a nut operating over a split-taper thread. Experiments made with 25,000 volts through 16,000 ohms resistance showed no appreciable difference in the spark distance with and without the resistance in circuit.

The writer believes that under the right conditions accurate results can be obtained with a properly designed apparatus. A number of the points shown on the curve of Fig. 1 were made months after others, and the close agreement is an indication of the accuracy obtainable.

If this paper will stimulate investigations in connection with this very fascinating subject, the writer believes that the spark distance method may become as reliable as it is easy to apply. Before this condition is reached, however, many tests will have to be made with widely different generating and transforming apparatus, both open-circuited and connected to cables, etc.

These experiments show that the best results are obtained by the use of very sharp points; that large concave discs make the spark distances more uniform; that with infinitely sharp points the spark distance curve up to at least 10,000 volts would probably be a straight line passing through the origin and having an equation.

Spark distance in inches $= .000{,}054 \times$ volts.

In conclusion, the writer wishes to acknowledge his thanks to Mr. Shakarian for much valuable assistance rendered in these researches. Also to the Westinghouse Electric & Mfg. Company, and finally to the Standard Underground Cable Company for the use of instruments and construction of special apparatus employed in the tests.

TABLE I.

Water resistance setting.	Water resistance in ohms.	Increase of sparking distance multiplying factor.
5	17	1.000
10	35	1.000
15	58	1.000
20	98	1.001
22	118	1.001
24	139	1 002
25	150	1 004
26	163	1 007
27	180	1.011
28	195	1.017
29	210	1 025
30	225	1.040

TABLE II.—DISTANCE BETWEEN DISCS, 1 INCH.

Sparking distance in inches.	Mean effective voltage.	Diameter of points in .0001 inches.	Discs used.
			"A"
1.309	25,200	No. 12 T.H.P.B.	10 inch.
1.311	"	"	10 "
1.311	"	"	10 "
1.309	"	"	10 "
1.341	"	"	None.
1.325	"	"	"
1.318	"	"	"
1.321	"	"	"

TABLE III.—DISTANCE BETWEEN DISCS, ½ INCH.

Sparking distance in inches.	Mean effective voltage.	Diameter points in .0001 inches	Discs used.
.025	1001	5 F. 4 R. 4 F 5 R.	10 inch.
.0125	"	15.16 F. 15.16 F	"
.026	"	4.3 R. 4 3 R.	"
.012	"	7.9 R 8.8 R.	"
041	"	2.2 S. 2 2 S.	"
040	"	2 F. 2 S 2 2 S.	"
.0115	"	20 F. 15 R. 20 F 15 R.	"
.025	"	3 3 R. 3.3 R.	"
014	"	5 5 R. 6 6 R.	"
.0235	"	5 5 F. 6 6 F.	"
.012	"	50 50 F. 50 50 F	"
.006	"	Pin heads.	"
.034	"	Pin head, 2 2 S.	"
.0075	"	20 20 F. 20.20 F.	"
.0025	1028	Pin heads.	"
.0515	1000	Very sharp points	"
.048	"	" " "	"

TABLE IV.—DISTANCE BETWEEN DISCS, 1 INCH.

Sparking distance in inches.	Mean effective voltage	Diameter of points in .0001 inches	Discs used	
		A		
344	6,200	3—4 F 3—5 F	10 inch	
344	"	8—7 F 8—7 F.	"	
.388	"	7—7 F 7—6 R	"	
.380	"	20—20 F 20 20 F	"	
398	"	No 12 T H P B.	"	
370	"	50 50 F 50.50 F	"	
341	"	3 S 3 R 2 S 2 R.	"	
422	"	15 15 F 20 20 F.	"	
374	"	30 30 F 25 25 F.	"	
381	"	40 40 F 45 45 F	"	
369	"	14 14 F 15 15 R	"	
.316	"	5.5 R 5 5 R	"	
413	"	13 F 13 F 13 13 F	"	
.331	"	8 8 F 8 7 F	"	
.408	"	16 16 F 16.16 F.	"	
393	"	17 17 R. 17.18 R	"	
.414	"	15 15 R. 13.15 R.	"	
.407	"	10.10 F 10.18 F.	"	
		B		
380	"	14 F. 12 R 4.3 R.	"	1
.335	"	12. 14 R 5 R. 4 F.	"	2
.334	"	15. 15 F 4 F. 5 R.	"	2
.355	"	15 F. 14 F 4 4 R.	"	1
334	"	14 14 F 5.4 R	"	2
.411	"	15.17 R 5.4 R.	"	1
.393	"	16 16 R 3.4 R.	"	1
.333	"	18 18 R 4.5 R.	"	2
.340	"	17 F. 15 R 3.4 R.	"	2
.336	"	17 F. 15 R. 5 5 R.	None.	1
.337	"	18 F 18 R 5.5 R	"	1
.380	"	18 F. 18 R. 5.5 R	"	2
.369	"	18 F 17 R 5.5 R.	"	2
.335	"	18.18 F. 5.5 R.	"	1
.372	"	18.18 F. 4 4 R	"	2
		C.		
.391	"	18 F. 19 R. 3 3 R.	4 inch	2
.392	"	17 F. 18 R. 3 3 R	"	2
.376	6,184	20 F. 20 R 3 R. 2 S.	"	1
.378	6,196	20 20 F 2 S 3 R.	"	2
.381	"	19.21 F. 2 2 R	"	1
.393	6,184	12.12 F. 2.2 F	"	2
.393	6,196	12.15 F. 2 R 2 F.	"	1
.336	"	6 F 7 R. 7.7 R.	"	
		D		
.337	6,200	2 4 R. 2 4 R	10 inch	
333	"	2.4 R. 3 F 2 R.	"	3
.338	"	3 F 4 R 2 F 4 R	"	4
.336	"	5 F 3 R. 5 F 3 R	"	3
.335	"	5 F. 4 R 5 F 4 R	"	4
.335	"	4 R. 4 F. 4 R 4 F.	None.	
.336	"	4 F 5 R. 5 F. 3 R	"	3
		E.		
.338	"	3 F. 4 R 3 F 3 R	4 inch	
.336	"	5 5 R 5 5 R	"	
.342	"	3 3 F 3 3 F.	10 inch	
.336	"	3 R 3 S. 2 F 2 S.	"	

1. Large point near handle.
2. Small point near handle.
3. Other side grounded.
4. Handle side grounded.

Table V.— Distance between Discs, 1 Inch.

Sparking distance in inches	Mean effective voltage	Diameter of points in .0001 inches.		Discs used.	
				A	
548	10,100	3 F 3 R	3 F. 3 R.	10 inch	
551	"	4 F 4 R	4 F 2 R.	"	
642	"	18 18 R.	18 18 R.	"	
638	"	18 18 R.	18 18 R	"	
.625	"	28 28 F.	28 28 F	"	
544	"	12 12 F	11 11 F	"	
561	"	15 15 F.	14 14 F.	"	
539	"	No. 12 T. H P B.		"	
540	"	"		"	
630	"	22 22 F	22 22 F.	"	
643	"	17 17 F	17 17 F.	"	
639	"	15 15 R.	15 15 R.	"	
608	"	30 30 F.	30 30 F	"	
617	"	14 14 R	13 13 R.	"	
610	"	10 10 R	10 10 R.	"	
.547	"	4 5 R	4.5 R.	"	
				B	
631	"	17 17 F.	3 5 R	10 inch.	1
619	"	3 4 R	17 17 F.	"	2
626	"	25 25 F	4 5 F	"	1
.612	"	25.25 F	5 5 F.	"	2
				C.	
600	"	22 22 F.	6 F. 5 R.	4 inch.	1
.604	"	22 22 F	6 F 5 R	"	2
620	"	18 18 F	4.3 R	"	1
619	"	18 18 F	5 F 2 R.	"	2
				D.	
629	"	20 20 F	4 5 F.	None.	1
652	"	20.20 F	5 3 F.	"	2
.652	"	20 20 F	3 3 R.	"	1
644	"	20 20 F	3.3 R.	"	2
				E.	
548	"	No. 12 T H.P.B.		4 inch.	3
.548	"	"		"	4

1. Large point on handle side.
2. Small point on handle side.
3. Handle side grounded.
4. Other side grounded.

Table VI.—Distance between Discs, 1 Inch.

Sparking distance in inches	Mean effective voltage.	Diameter of points in .0001 inches	Discs used.	
			A	
1.047	20,200	3 3 R 3 4 R	10 inch	
1 044	"	6 F. 7 R 7 F 6 R	"	
1 048	"	16 F 18 R 16 16 R	"	
1.075	"	30 29 F 30 29 F.	"	
1.067	"	24 26 F 24 26 F	"	
1 055	"	22 22 R. 23 23 R	"	
1 052	"	22 22 F. 22 22 F.	"	
1 061	"	20 22 F 20 20 R.	"	
1.059	"	36 35 F. 33 33 F.	"	
1 051	"	29.30 F 29 30 F.	"	
			B	
1 053	"	4 6 F 26 25 F.	10 inch	1
1 039	"	4 F. 5 R 26 25 F.	"	2
1 045	"	4 4 R 5 5 R	"	
1 048	"	6 F. 4 R 6 F. 7 R.	"	3
			C	
1 047	"	No. 12 T H.B P.	10 inch	4
1 052	"	"	None	
1 071	"	"	"	3
1 061	"	"	"	3
1 054	"	"	"	4
1 060	"	"	"	3
			D	
1 053	"	No. 12 T.H.P B.	None	5
1 048	"	"	4 inch	
1 060	"	"	"	3
1 055	"	"	"	3
1 056	"	"	"	4
1 047	"	"	"	5
1 060	"	"	"	3
1.048	"	"	"	3

1. Large point near handle.
2. Small point near handle.
3. Handle side grounded
4. Other side grounded
5. No grounding

Table VII.—Distance between Discs, 1 Inch.

Sparking distance in inches.	Mean effective voltage.	Diameter of points in .0001 inches.	Discs used.
			A.
1.585	30,200	No. 12 T.H P.B.	10 inch.
1.580	"	"	10 "
1.583	"	"	10 "
1.580	"	"	10 "
			B
1.591	"	"	None
1 602	"	"	"
1.607	"	"	"
1 599	"	"	"
1 601	"	"	"
1.608	"	3 R. 2 S 2 2 S.	"
			C
1.913	"	27 27 F 27.26 F.	10 inch
2.000	"	25 24 F 25 26 F.	10 "
2.092	"	28 28 F 28 28 F.	10 "
2.145	"	20 20 F 21 20 F.	10 "
2 193	"	19.20 F 20 23 F	10 "
2.220	"	17 17 F. 18.16 F	10 "
2.170	"	23 25 F. 23 25 R.	10 "
2 336	"	16 20 R 15 15 R.	10 "
2.401	"	23 24 F 23 21 F	4 "
2 302	"	18 F. 18 R 13 F. 18 R	None.
2 320	"	17 17 F. 19 17 F	"

TABLE VIII.—MEAN EFFECTIVE VOLTAGE, 40,000.

Sparking distance in inches.	Diameter of points in .0001 inches	Discs used	Distance between discs.
		A.	
2 121	4 6 F 4 6 F	10 inch	1½ inches.
2 125	No 12 T.H P.B.	10 "	2 "
2 150	"	10 "	2 "
2 146	5 F 2 S 2 F 2 S.	10 "	2 "
2 120	3 3 R. 3 3 R	10 "	1½ "
2 131	3 3 R 4 3 R	10 "	3 "
		B.	
2 211	No 12 T.H P B.	None.	
2 241	"	"	
2 226	"	"	
		C.	
2.195	17 18 F. 17.18 F.	None.	
3 160	23 25 F 25 27 F.	"	
2 969	17 18 F 17 18 F.	10 inch	2 "
2 985	17 17 F 17 17 F.	None	
		D	
3 083	23 25 F 5 3 R.	10 inch.	2 "
2 972	19 19 F 3 4 F.	10 "	2 "
		E.	
2 086	7 F. 6 R 7 F. 6 R.	10 inch.	2 "
2 093	6 F. 7 R. 6 F 7 R.	10 "	2 "
2 117	5.7 R 5 6 R.	10 "	2 "
2.159	4 5 R 5 6 R.	10 "	2 "

1. Large point near handle
2. Small point near handle.
3. Handle side grounded.
4. Other side grounded.

TABLE IX.

Volts.	SPARKING DISTANCES, IN INCHES.		
	A. I. E. E.	FISHER'S	
		Discs.	No discs.
10,000	.470	.540	.....
20 000	1.000	1.040	....
25,000	1 300	1.300	1 314
30,000	1.625	1.580	1.600
40,000	2 450	2.140	2 220
45,000	2 950	2.440	2.580
50,000	3.550	2.770	.....

DISCUSSION.

DR. LOUIS BELL: The topic of Mr. Fisher's paper is one that is most pertinent in high-voltage work, inasmuch as at the pressures now used the ordinary instrumental methods are subject to considerable errors, and are rather difficult to apply; so that there are many cases of high-pressure transmission work where the power of quantitatively using this sparking-distance method would be very valuable. The interesting feature of the paper seems to me to be the tendency of these points to accumulate in

a straight line. The straight line relation is just what we want if it will kindly hold through over a wide range of voltages.

Mr. C. E. SKINNER: A few years ago the American Institute of Electrical Engineers adopted as a standard for high-voltage measurements the striking distances between needle points, for e.m.f s up to 150,000 volts, also specifying a definite method of procedure in making insulation tests, using this method for determining the voltage of test. In the use of this method it was found that the sparking distances varied for conditions which, as far as could be determined, were exactly the same, these variations being as much as 10% or even more. Consequently, the tests were not reliable, and when very high voltages were used, this amount of variation might lead to considerable trouble. It is only through such careful methods as those described by Mr. Fisher and by the use of some of the devices he has described, that any reliability is assured in the use of a spark-gap for measuring the voltage of a testing circuit. The speaker has known something of Mr. Fisher's work during its progress, and wishes to express his appreciation of the painstaking care which Mr. Fisher has exercised in the carrying out of this work. It is no easy thing to secure needles that are still sharp under a magnification of 600 diameters, to line them up, and to measure the distances between their points, but Mr. Fisher's results show that he has successfully accomplished this work. Another difficulty encountered in the use of spark-gaps for insulation testing purposes, was the rush of current and consequent rise of potential on the outer turns of the testing transformer and in some cases on the turns of the apparatus tested.* The use of a resistance in series with the spark-gap obviates this difficulty, and it is very gratifying to know from Mr. Fisher's work that the use of such a resistance is allowable.

Dr. BELL: I would like to ask Mr. Fisher two things with respect to the curves given. First, using the regular commercial needle of such type as he gave there, what is the error introduced into the curve? What percentage of error is introduced by the use of a supply of commercially sharp needles rather than by those which are carefully sharpened for the purpose in making tests? And, second, whether he detected any error due to condenser action on the discs as a possible disturbing cause in the sparking distances? At the high voltages I particularly noted that the difference between sharp and blunt points seemed to disappear or reverse or change in various ways, and it at once occurred that with these large discs at thirty, forty, fifty, sixty thousand volts, the condenser action might cut a very considerable figure in modifying the conditions of strain or even the effective voltage at the discharge points.

Mr. FISHER: Answering Doctor Bell's first question I will say that the error introduced by this kind of points varies with different voltages. If you are making tests at about 1000 volts, the error may be very great indeed, because it is possible to have needle points, taken from an ordinary pack of needles, which will give spark distances varying from .012 inch to .040 inch. With 10,000 volts, the points can vary from .000,2 inch to .000,8 inch without effecting the sparking distance to any appreciable degree; above .000,8 inch the sparking distance increases until a maximum

is reached near .002 inch. Now there seems to be a kind of law which is true in most instances and which may be stated as follows· Given two kind of points, a spark distance will correspond to that point which when tested with a similar point gives the maximum spark distance. To illustrate, at 1000 volts, a maximum spark length is produced with sharp points. If a test is made with one sharp point and one blunt point, the spark length will correspond to that obtained with sharp point. While with 10,000 volts a maximum sparking distance is obtained with points about 002 inch in diameter, and if a sharp point is used with another point measuring about .002 inch in diameter, the spark length will correspond to that of the blunt point which in this case gives a maximum distance. On account of this fact and because a pack of needles may contain both sharp and dull points, one spark length test can not be relied upon where accuracy is desired. But as I said before if you will examine the brush discharge at the points and get familiar with its appearance under normal conditions, you can at once tell, at the time of the discharge, whether the condition is regular or abnormal. If it is a regular condition, as you advance the needle points you will get a gradually increasing brush which, near the normal sparking distance, becomes much more pronounced, and under normal conditions, by observing said brush discharge, it is possible to tell when the spark will occur within a few thousandths of an inch, with pressures above 6,000 volts. Now, if you happen to have a dull point, which will give a longer sparking distance than is obtained with sharp points, you will not get the normal brush discharge, a spark occurring before the points are close enough to produce the normal effect. In like manner by observing the brush discharges, you can tell if the spark is produced by an impulsive rise of voltage due to resonance, etc. As stated in the paper it is possible to get large errors when the points are not measured. But if you make several tests and you eliminate the erratic ones good results can be obtained.

Dr. Bell: Take a paper of No. 12 sharp needles and use them, we will say, for experiment, at 10,000 volts and upwards; how large an average deviation would you get from your curve as you substitute one of these needles from the same paper for another? In general, how large an error are you likely to introduce, if you work with your standard commercial needles without calibrating their points?

Mr. Fisher: I will speak of 25,000 volts first because this was the reference voltage and there were tests made every time at this voltage. At 25,000 volts we found that the distances should agree within 3 or 4 thousandths of an inch when the operating conditions were normal, and that is practically true also at 10,000 volts. But as I said in making these tests, you may get abnormal spark distances due to the points not being sharp or to causes connected with the operation of the generator.

Dr. Bell: You are answering the theoretical part of the question most efficiently; but what I am trying to get at is this: If I take a paper of needles, lining them up carefully and going to work, we will say, at twenty or twenty-five thousand volts, and so on, up to forty or fifty or sixty thousand volts, how great casual errors am I likely to introduce — how

much departure from your curve — by the different sharpness of the needles as they commercially exist, as you take them out of the paper?

Mr. FISHER: I might say offhand that in two or three tests you are not apt to get much more variation than 2 or 3% and often the agreement is very much closer than this.

Dr. BELL: That is very satisfactory. Could you trace any effect of the condenser action of these guard plates, when it came to those higher voltages?

Mr. FISHER: Only in this way, that the sparking distance is less when the guard plates are used for voltages above 23,000 volts; but if the plates are set within one-fourth of an inch of the same distance back of the needle points every time, the results are consistent, and agree better with plates, than without them.

Chairman SCOTT: In electrical work we have been restricted to the use of a few definite materials. The three general classes are iron, copper and insulation. There is nothing which can take the place of iron; there has, until recently, been nothing which takes the place of capper, but aluminum has been a formidable rival of copper in transmission work during the last few years. Copper has had many years of evolution. The ways of drawing the wire, its physical characteristics, adapting it both electrically and mechanically to its purposes, have been worked out by years of experience. Aluminum has come into the field within a few years, and it is quite an important matter to have its physical characteristics and mechanical constants. These are being developed by experience and each year brings to us new data. Mr. Buck, electrical engineer of the Niagara Falls Power Company, has been giving the matter especial attention and his paper, which will now be presented, deals with that subject.

THE USE OF ALUMINUM AS AN ELECTRICAL CONDUCTOR.

BY H. W. BUCK.

About the year 1898, the price of aluminum had been so reduced by the commercial application of the Hall process, that this metal began to come into prominence as a competitor of copper for use as an electrical conductor. In physical characteristics, aluminum differs materially from copper. Its properties give it some advantages, and some disadvantages. Some of its physical constants as it is now manufactured commercially for electrical purposes are as follows: Melting point, 1157 deg. Fahr.; elastic limit, 14,000 lbs., per sq. in.; ultimate strength, 26,000 lbs. per sq. in.; modulus of elasticity, 9,000,000; electrical conductivity, 62 per cent; specific gravity, 2.68; co-efficient of linear expansion, .000,012,8.

On account of its properties, aluminum is not applicable to all the purposes for which copper is used electrically. At present its electrical utility is confined to (a) bus-bars, (b) high-tension overhead uninsulated conductors, (c) low-voltage feeders, usually insulated with weatherproof braid only.

Aluminum is barred from use in a number of cases on account of the practical impossibility of applying the ordinary methods of soldering. Its surface seems to have a coating of oxide on it at all times, which prevents the adhesion of the soldering metal.

At the present relative cost of the two metals, aluminum is about 10 per cent, or 15 per cent, cheaper than copper of the same resistance. The weight of a unit length of aluminum wire is only 47 per cent of a copper wire of the same length and resistance. Consequently aluminum can cost $\frac{1.0}{0.47} = 2.13$ times as much as copper per pound and still cost the same as copper per unit length from the standpoint of electrical resistance. As a matter of fact, however, the price of aluminum at present is less than 2.13 times that of copper per pound, so that it is actually cheaper to use aluminum as an electrical conductor than copper, where other considerations do not enter.

Use for Insulated Cable.

For all forms of wire and cable which have to be insulated with expensive materials, such as rubber, aluminum is at a decided disadvantage. Its lower conductivity necessitates a greater diameter than a copper conductor of the same resistance, and the extra cost of insulation required to cover the aluminum prevents it from competing with copper for this particular purpose on the basis of the present relative costs of the two metals.

Interior Wiring.

The difficulty in soldering aluminum wire conveniently, and the greater cost of covering it with insulation, renders its use for interior wiring practically out of the question.

Telephone Wires.

The high co-efficient of expansion of aluminum wire, and its comparatively low tensile strength, causes a greater sag at high temperatures than with copper in overhead line work. In telephone construction, where the wires, by necessity, are strung close together on the crossarms, this greater sag of aluminum would probably result in contact between wires at the deflections which would occur at summer temperatures. For this reason, together with the soldering difficulty, where lateral connections are made, aluminum is practically shut out of competition with copper for this particular use. There is also some objection to the use of aluminum wire as small as that required for telephone purposes, on account of the necessity of stranding it. There is no reason, however, why aluminum should not be used as a conductor for isolated aerial telephone lines, if a large enough wire can be used. In cases known to the writer where it has been used for such telephone circuits, it seems to have operated as a particularly good carrier of the voice. This may possibly be due to the particular balance which exists in an aluminum wire between resistance, inductance and capacity, aluminum having somewhat less self-induction, and more capacity, than a copper wire of the same resistance.

Bus-Bars.

Aluminum is particularly well suited for bus-bar constructions. Here no insulation is usually required over the bus-bar metal, while the great saving in weight, and the lower cost, are decided advan-

tages in favor of aluminum. Care should be taken, however, in using aluminum for such purposes, to provide for expansion and contraction with changes in temperature, which is greater in aluminum than in copper. The increased section of an aluminum bar over a copper bar of the same resistance, affords greater radiating surface and allows a given current to be carried with a lower rise in temperature. Consequently, for a given temperature rise, which is usually the limitation in a bus-bar installation, and not "drop," an aluminum bar will weigh only about 38 per cent of a copper bar for the same heating. This is an obvious advantage for aluminum. Such bars are being used extensively for carrying currents of very large volume, such as are required in low-voltage electrolytic plants.

Low-Voltage Feeders.

A very wide application of aluminum has developed for low-voltage direct-current feeders, especially for railway work. Sizes up to 2,000,000 cm are in use for railway feeders, the cables being usually covered with weatherproof braid. Aluminum has many especial advantages for this purpose. The quality of the poles and crossarms frequently installed for the support of railway feeders is not of the best, and the 53 per cent reduction in weight in the use of aluminum saves in maintenance and in line breakdowns. The cost again enters as a 10 per cent or 15 per cent advantage. Furthermore, the increased radiating surface of the aluminum feeder allows a greater overload to be carried by it than with copper, without melting out the compound of the weatherproof braid, which happens so frequently in copper feeders from overheating, when cars become bunched on the line.

High-Voltage Overhead Lines.

The most prominent use of aluminum, electrically, and the one over which there has been the greatest amount of discussion, is that for overhead high-voltage transmission circuits. When aluminum was first introduced for overhead conductors, it was furnished in the solid form. Considerable trouble was experienced with this kind of wire from breakage resulting from flaws in the metal, and from "crystallizing" of the wire from swaying in the wind. About the year 1900, the stranded form was substituted for even the smallest sizes (No. 4 B. & S.), and the original trouble from breakage has been entirely eliminated.

The writer has communicated with most of the principal users of aluminum wire in this country, in order to establish, by the expression of opinion of prominent engineers, the position of aluminum as an overhead conductor in comparison with copper. The replies to these inquiries have brought out the following points:

1). That the experimental stage in the manufacture of aluminum wire has passed, and that the product, as now furnished by its manufacturers, is entirely reliable, and up to the guarantees made for it.

2). That there is no appreciable disintegration of aluminum wire from ordinary atmospheric conditions. Certain special cases have been reported of corrosion, all of them affecting short lengths of wire only. One where wires were subjected to chemical fumes from factories, and others where the wire was exposed continuously to salt fog on the Pacific coast. It is probable that any metal would have been affected by this action. Under usual conditions, however, even on the sea-coast, aluminum is a durable metal. Weather-proof insulation serves as an effective protection against corrosive influences, when not accompanied by continuous moisture which will keep the weather-proof braid saturated. The Niagara Falls Power Company has successfully protected its aluminum line with weather-proof braid where it passes through the chemical-factory district. On the sea-coast, where the atmosphere is damp, aluminum should not have weather-proof covering, for the above reason. The metal will protect itself by thin impervious coating of oxide, which is better than any artificial covering.

3). That no trouble is being experienced with the stranded aluminum wire in breaking from flaws, "crystallizing," etc.

4). That aluminum wire gathers much less sleet than copper. This is perhaps due to the grease which is absorbed in the aluminum due to its porous qualities, in the process of wire drawing or from some other physical condition of its surface.

5). That it costs less to string aluminum wire on account of its lighter weight.

6). That care must be taken in stringing aluminum wire in rough country on account of its softness; stones or rough places on the ground causing considerable abrasion, where the wire is dragged along the ground.

7). That the mechanical and splice joints as now used on aluminum wire are entirely satisfactory without the use of solder.

8). Care should be taken in the design of an aluminum pole

line to place the wires as far apart as possible, in order to avoid trouble from burning-off of the wire in case of a short circuit. The melting point of aluminum is much lower than that of copper, and the damage from a prolonged arc is therefore greater. If the wires are placed sufficiently far apart, any arc which may be formed will be so unstable that it will travel rapidly with the wind, or by magnetic repulsion, and will not stay long enough in any one spot to cause any appreciable burning.

The fundamental consideration which enters into the use of aluminum for overhead line work is that of wind pressure, and especially so in modern long-span construction problems. In order to obtain some direct observations of wind pressure on stranded cables, the writer has been carrying on some observations upon an experimental 950-ft. span constructed for the purpose at Niagara Falls. The strong winds at Niagara have the convenient property of always blowing from the exact southwest. This experimental span was therefore erected to run southeast and northwest so that the strong winds would blow directly at right angles to the cable in the span. The supports of the span were 45 ft. in height and placed 950 ft. apart. At the center of the span a platform was erected at such a height that the cable would be accessible at the exact center. A government standard anemometer was set up on this platform, having its contacts arranged to indicate the time for every one-quarter mile traversed by the wind. A wind vane was also erected on the platform to indicate the exact direction of the wind. Dynamometers were arranged on the platform to indicate the wind-pull on the cable. On the floor of the platform, which was within a few inches below the center of the suspended cable, was carefully marked the exact center of the span, and the spot over which the exact center of the cable hung when the cable was not subjected to any wind pressure. When the wind blew directly across the line, a dynamometer was attached to the exact center of the cable, and the cable drawn back from its wind-deflected position to the center spot on the platform described above. The pull in pounds on this dynamometer was then observed with the cable at its central position, and the wind velocity observed at the same time. The pull at the center then, as indicated by the dynamometer, represented one-half the total side pressure due to wind on the cable, the other half of the side thrust being divided equally between the two end supports. This dynamometer reading, therefore, multiplied by two, and divided

by the projected area of the cable in square feet, gave directly the wind pressure per square foot on the cable. Fig. 1 shows the results of these observations to date. The highest wind velocity experienced so far has been 40 miles per hour indicated ($33\frac{1}{2}$ miles per hour actual). The curve drawn represents about the average of all the observations and it is expressed by the formula

$$P = .0025\ V^2$$

where P = pressure per square foot of projected cable area, and V = actual velocity of wind (not indicated velocity) in miles per

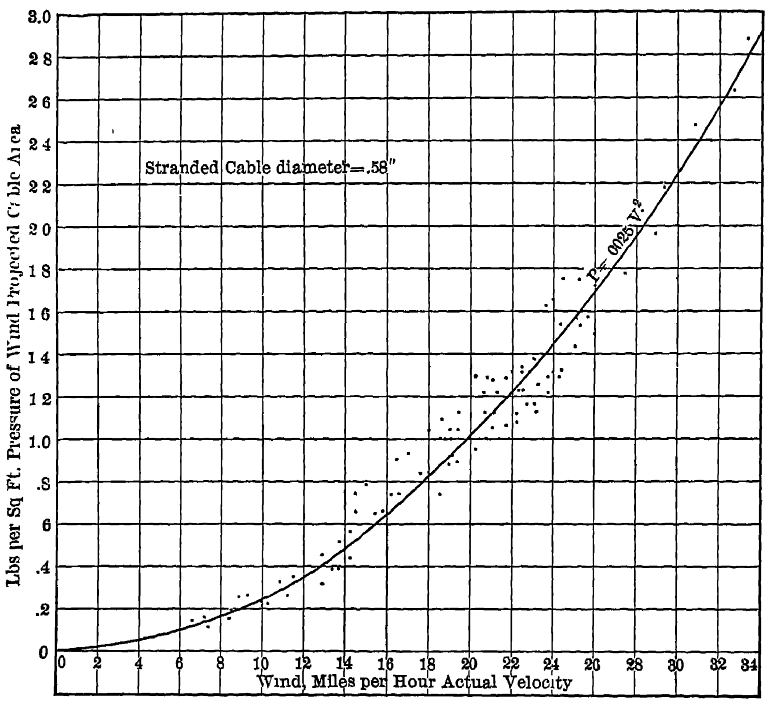


FIG. 1. WIND PRESSURE CURVE.

hour. The reason for variance in the observations is due to the fact that the wind-pull on the wire observed was proportional to the average wind velocity throughout the whole span, whereas the wind velocity observed by the anemometer, in connection with the pull, was merely that at the center of the span. The average of the observations, however, is believed to be close to the correct figure. The observations will be continued during the coming

winter, and it is hoped that the curve can be extended by some records at higher wind velocities.

The equation $P = .002\ V^2$ has been established by some other experimenters on wind pressures for cylindrical surfaces. The fact that the constant in the writer's observations has been higher than this is believed to be due to the fact that a stranded cable offers greater resistance to the wind than a pure cylinder of the same diameter.

In the curves and tables given in this paper showing the relation between span-length, deflection, temperature, etc., the equation $P = 0.0025\ V^2$ is taken as a basis for wind pressure.

Having determined the value of wind pressure for a given velocity, it is next of equal importance to determine the maximum velocity to which a transmission line is likely to be exposed. A study of the records of the United States Weather Bureau brings out the following points:

1). The wind velocities reported by the United States weather stations are *indicated* velocities, not *actual* velocities, the correction factors being shown in the following table:

Indicated velocity, miles per hour.	Actual velocity, miles per hour.
0	0
10	9.6
20	17.8
30	25.7
40	33.3
50	40.8
60	48.0
70	55.2
80	62.2
90	69.2
100	76.2

2). Maximum wind velocities do not occur at very low temperatures.

3). The highest regular winds occur on the actual sea-coast, the exception being tornadoes of very narrow path, which usually occur inland and which blow at unknown velocities, probably 200 miles per hour, or more.

4). With the exception of tornadoes, and gales which blow on the tops of high peaks, Point Reyes, Calif., and other places which

might be considered as freak localities, the highest winds recorded do not exceed 100 miles per hour indicated, or about 76 miles per hour actual velocity. Winds of even this velocity occur only on the sea-coast and are seldom, if ever, experienced inland. The following figures show the highest winds on record for the past ten years at some of the cities in this country (tornadoes excepted, which are not on record):

Place.	Wind velocity, indicated, miles per hour	Wind velocity, actual, miles per hour.
Bismark, N. D.	72	56.6
Eastport, Me.	78	60.8
Buffalo, N. Y.	90	69.2
New York City	78	60.8
Galveston, Tex.	84	65
Savannah, Ga.	76	59.4
Salt Lake City	60	48

None of the above winds blew at very low temperatures.

5). The records of the Weather Bureau are all taken at high points, such as at the tops of high buildings, etc., which are 100 feet or more above the ground. The wind velocity decreases rapidly as the ground level is approached, and at the level of an ordinary transmission line, the velocity is about 30 per cent less than at a point 100 feet or more above the ground.

Assuming then that 100-miles-per-hour indicated velocity is the maximum likely to be experienced at the elevation of a weather station, this would be only 76-miles-per-hour actual velocity, and 30 per cent less for the level of a transmission line, or about 55 miles per hour actual. According to probabilities, even this would not occur at minimum temperatures.

In the curves which are given in this paper, 65 miles per hour actual velocity at minimum temperature is taken as a basis for maximum wind-pressure, and it is believed that this is high enough to meet any probable wind stress except that due to a tornado. The speed of 65 miles per hour at minimum temperature corresponds to about 80 miles at maximum temperature in the stress which it produces on a wire. In regard to tornadoes, their velocity is so high that it is commercially impossible to build all lines strong enough to withstand them. It must be remembered that even if the wind should exceed the velocity assumed in this paper

as a safe commercial maximum, the worst that could happen would be a stretching of the wire up to a new deflection corresponding to the higher wind-tension. The reduction in area of the wire

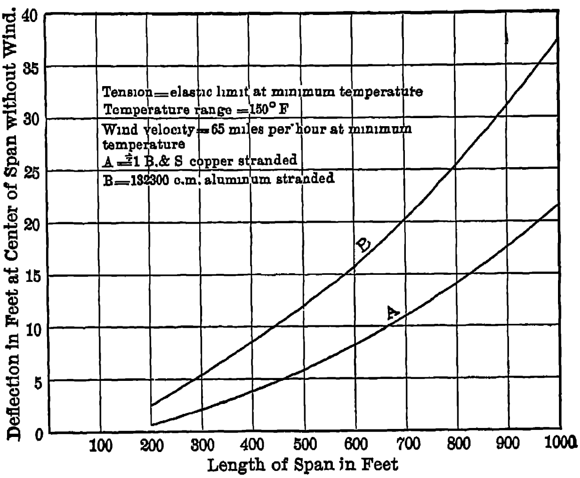


FIG. 2. DEFLECTION CURVE AT MAXIMUM TEMPERATURE.

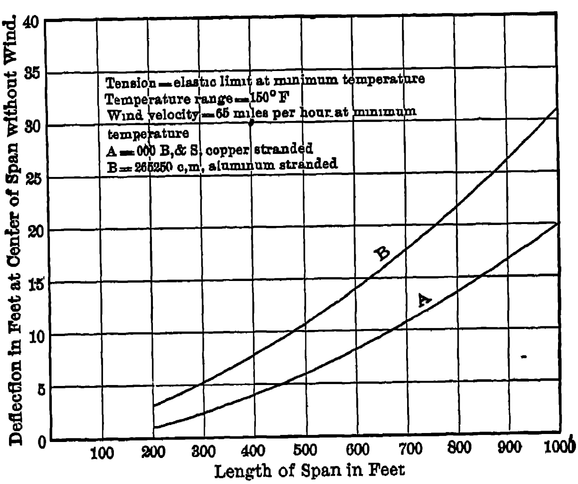


FIG. 3. DEFLECTION CURVE AT MAXIMUM TEMPERATURE.

would be only a small fraction of one per cent, and the slack could be taken up in a few hours' work after the wind had passed.

Figs. 2, 3 and 4 show the comparative deflections between aluminum and copper for various sizes of conductor, for span-lengths from 200 ft. to 1,000 ft. The deflection shown is that which would result at 150 deg. F. above the minimum temperature without wind, if the line was strung so that at minimum temperature, and 65-miles-per-hour actual wind velocity directly at right angles

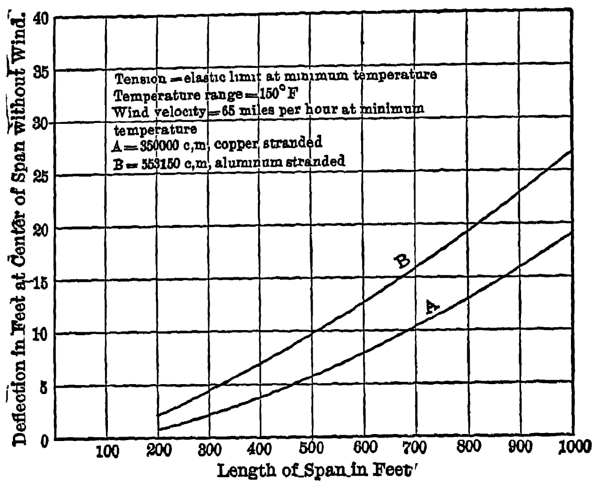


FIG. 4. DEFLECTION CURVE AT MAXIMUM TEMPERATURE.

to the line, the wires would be stressed to their elastic limit. The following data are assumed in all the calculations:

	Aluminum.	Copper.
Elastic limit per sq. inch...........	14,000 lbs.	40,000 lbs.
Coefficient of expansion per deg.	0.000,012,8	0.000,009,6
Modulus of elasticity.............	9,000,000	16,000,000
Temperature range................	150° F.	150° F.
Wind velocity at min. temp., per hr.	65 miles	65 miles
Wind pressure per square foot.....	10.5 lbs.	10.5 lbs.

It will be noticed from the curves that the deflection is larger with small wires than with large ones. This results from the fact that the strength to resist wind pressure increases in proportion to the square of the diameter of the wire; whereas the wind pressure increases only directly as the diameter. Fig. 5 shows the deflections which would exist if there were no wind stresses.

Aluminum in this case closely approaches copper in deflection. This curve in comparison with curves 2, 3 and 4 illustrates the importance of taking wind pressure into consideration in all calculations for long-span constructions.

This question of deflection at maximum temperature without wind is of vital importance for it determines the height of the supports necessary to keep the conductor at a safe distance from the ground under extreme temperature conditions. This height of support establishes to a considerable extent the cost of the transmission line, and it is an especially important matter in long-span constructions.

An inspection of the curves shows that aluminum is at a disadvantage compared with copper in this matter of deflection where long spans are considered. For example, supports for 400-foot

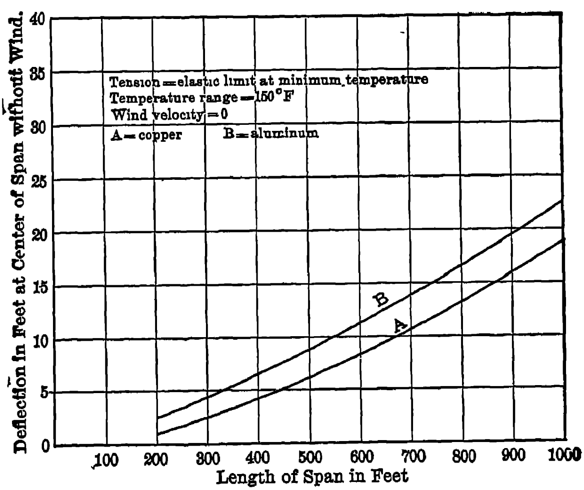


FIG. 5. DEFLECTION CURVE AT MAXIMUM TEMPERATURE.

spans of aluminum of 265,000 cm section will have to be 3.4 ft. higher than the supports for equivalent copper. For spans of 300 feet or less the matter of deflection is unimportant, for it makes little difference whether the deflection is two feet or three feet, more or less. But in very long spans where the difference may be 20 feet in the case of copper and 30 feet in aluminum, the question of deflection is of considerable moment, and the advantages are in favor

of copper. The height, therefore, of a support for a long-span line of aluminum would have to be greater than for a copper line. Its strength, however, need not be so great as would be required for the support of a copper span. The weight of the aluminum wire is only 47 per cent of the copper span of the same resistance, and, furthermore, the tension in the aluminum cables will be from one-half to one-third those of the copper ones, depending upon the temperature. Where there are bends in a line, and when each pole is designed to withstand unbalanced strains due to the breaking of one or more wires, the lesser weight and tension on the aluminum cables is a decided advantage which offsets, in a measure, the increased height required for the aluminum supports.

No account of the extra weight, due to the formation of sleet on the wire, is taken in the calculations in this paper, for it does not seem to be the experience of most engineers that sleet forms on high-voltage wires. This is, perhaps, due to the electro-static repulsion of the particles of water from the wires, which prevents their forming into sleet, or else a sufficient rise in temperature exists in the wire due to current to prevent freezing. Sleet would certainly not stay on a wire during a high wind.

Table I gives the resistance and other properties of pure aluminum cable as now manufactured in sizes from No. 4 B & S up to 1,000,000 CM.

Table II gives the resistance and other properties of aluminum cable in sizes equivalent in resistance to standard sizes of copper from No. 6 B & S to 1,000,000 CM.

Table III gives the deflections which would occur at various temperatures without wind in three sizes of aluminum cable for various span lengths up to 1000 feet, the cable being stretched so that it reaches its elastic limit at minimum temperature with the wind blowing at 65 miles per hour actual velocity. The other constants are taken the same as in curves 2, 3, 4 and 5.

Table IV shows deflections at various temperatures and span lengths without wind for No. 2 B & S aluminum, the wire being stretched to its elastic limit at minimum temperature, with the wind blowing 65 miles per hour actual velocity. It is safe to follow this table for all sizes of cable, for the larger sizes will have slightly smaller deflections without exceeding their elastic limit on account of their greater relative strength.

Aluminum is a highly electro-positive metal. Consequently great care should be taken where contact is made with other metals to keep the joint free from moisture, otherwise galvanic action will be set up which will rapidly destroy the aluminum.

The fact that aluminum is one of the principal constituents of the earth's crust leads one to believe that some day its cost will be very low. If that condition ever arrives aluminum will probably become the principal metal for the conduction of electric current.

TABLE I.—DIMENSIONS AND RESISTANCES OF ALUMINUM CABLE. RESISTANCE AT 75° F. RESISTANCE PER MIL-FOOT, 62 PER CENT CONDUCTIVITY = 16.949 OHMS.

SIZE.	Diameter stranded inches.	Area square inch.	Pounds per 1000 feet.	Pounds per mile.	Feet per pound.	Ohms per 1000 feet.	Ohms per mile.	Elastic limit, pounds.	Ultimate strength, pounds.
1,000,000 CM	1.15	.7870	920	4,858	1.087	01695	.08950	10,995	20 420
950,000 CM.....	1.12	.7470	874	4,617	1.144	01784	.09420	10,440	19.400
900,000 CM	1.09	.7075	828	4,374	1 208	01883	.09942	9,900	18,380
850,000 CM.....	1.06	.6680	782	4,131	1.279	01994	.10529	9,350	17,360
800,000 CM.....	1.03	.6290	736	3,888	1 359	.02119	.11188	8,800	16,340
750,000 CM.....	1.00	.5890	690	3,645	1.449	02260	.11933	8,230	15,320
700,000 CM	.96	.5500	644	3,402	1 553	.02421	12782	7,700	14,300
650,000 CM.....	.93	.5120	598	3,159	1.672	02608	.13770	7,150	13,270
600,000 CM.....	.89	.4720	552	2,916	1.812	.02825	.14917	6,600	12,250
550,000 CM.....	.85	.4330	506	2,673	1 977	03082	.16275	6,050	11,230
500,000 CM.....	.81	.3930	460	2,430	2.041	.03300	.17900	5,500	10,210
450,000 CM.....	.77	,3540	414	2,187	2.415	.03766	.19884	4,950	9,190
400,000 CM	.73	,3141	368	1,944	2 718	.04237	.22370	4,400	8,170
350,000 CM.....	.68	.2750	322	1,701	3.106	04843	.25570	3,850	7,150
300,000 CM.....	.63	.2360	276	1,458	3.623	.05652	.29830	3,300	6,130
250,000 CM	.58	.1935	230	1,215	4 348	06780	.35800	2,750	5,110
0000 B & S...	.54	.1661	194.7	1,028	5 733	.08010	.42290	2,330	4,320
000 B & S...	.47	.1317	154.4	816	6 477	.10100	.53315	1,850	3,430
00 B & S...	.42	.1045	122.4	647	8.165	12740	.67270	1,460	2,720
0 B & S...	.37	.0829	97.1	513	10.300	.16050	.84740	960	2,150
1 B & S...	.33	.0657	77.0	407	12.990	.20250	1.0692	920	1,710
2 B & S...	.30	.0521	61.0	323	16.400	25540	1 3486	730	1,355
3 B & S...	.26	.0413	48 5	256	20,620	.32200	1.7002	579	1,075
4 B & S...	.23	.0327	38.5	203	25.970	.40600	2.1438	450	852

Elastic limit=14,000 lbs. per square inch.

Ultimate strength=26,000 lbs. per square inch.

TABLE II.—Dimensions and Resistances of Aluminum Stranded Cables Equivalent in Resistances to Standard Sizes Copper. Resistance at 75° F. Resistance Per Mil-foot, 62 Conductivity at 75° F. = 16.949 Ohms.

SIZE COPPER.	Aluminum equivalent. Circular mils.	Diameter. Aluminum. Stranded inches.	Area. Aluminum. Square inches.	Ohms per 1000 feet. Aluminum.	Ohms per mile. Aluminum.	Pounds per 1000 feet. Aluminum.	Pounds per mile. Aluminum.	Feet per pound. Aluminum.	Elastic limit. Aluminum.	Ultimate strength. Aluminum.
1,000,000 CM..	1,580,700	1.45	1 2415	.01072	.05660	1454	7678	.6878	17380	32280
950,000 CM..	1,501,700	1:41	1 1794	.01129	.05961	1381	7291	.7242	16510	30660
900,000 CM..	1,422,600	1 38	1 1172	.01191	.06288	1309	6912	.7640	15640	29050
850,000 CM..	1,343,500	1.34	1.0552	.01261	.06658	1236	6526	.8085	14770	27430
800,000 CM..	1,264,400	1.29	.9924	.01340	.07075	1163	6141	.8600	13900	25820
750,000 CM .	1,185,500	1.25	.9310	.01430	.07550	1091	5761	.9166	13030	24210
700,000 CM..	1,106,300	1.21	.8690	.01533	08094	1018	5375	.9824	12160	22590
650,000 CM..	1,027,300	1.17	8076	.01650	.08712	945.0	4989	1.0582	11300	20980
600,000 CM..	948,400	1.12	.7448	.01787	.09435	872.5	4554	1.1460	10430	19370
550,000 CM..	869,400	1.07	.6828	.01884	.09947	799 8	4223	1 2551	9560	17750
500,000 CM..	790,400	1 02	.6208	.02144	.11320	727.2	3839	1.8733	8690	16140
450,000 CM..	711,150	.97	.5586	.02383	.12580	654.4	3457	1.5282	7820	14520
400,000 CM..	632,300	.92	.4966	.02680	.14150	581.7	3071	1.7192	6950	12910
350,000 CM..	553,150	.86	.4345	.03064	.16180	509.0	2687	1.9648	6080	11300
300,000 CM..	474,200	.79	.3724	.03574	.18870	436.2	2303	2 2927	5210	9680
250,000 CM..	395,150	.72	.3103	.04289	.22650	363.5	1919	2 7511	4340	8070
0000 B&S.	334,450	.66	.2627	.05068	.26760	307.7	1625	3.2500	3680	6880
000 B&S.	265,250	.59	.2083	.06390	.33740	244 0	1288	4.0985	2920	5420
00 B&S.	210,300	.53	.1652	.08060	.42550	193 5	1022	5.1680	2310	4290
0 B&S.	166,850	.47	.1310	.10170	.53700	153.5	810.5	6 5150	1830	3410
1 B&S.	132,300	.42	.1039	.12810	67640	121 7	642.6	8.2170	1450	2700
2 B&S.	104,900	.37	.0824	.16160	.85320	96 5	509.5	10 3633	1150	2143
3 B&S.	83,190	.33	.0653	.20370	1.0760	76 5	403.9	13 0730	914	1700
4 B&S.	65,980	.30	.0518	.25690	1.3563	60.7	320.5	16 477	726	1350
5 B&S.	52,320	.26	.0411	.32390	1 7103	48.2	254.5	20 750	575	1070
6 B&S.	41,490	.23	.0326	.40850	2.1570	38.2	201.7	26.180	456	850

Conductivity copper calculated for 98, Matthiessen standard scale.
Elastic limit aluminum = 14,000 lbs. per square inch.
Ultimate strength aluminum = 26,000 lbs. per square inch.

TABLE III.—Deflections in Feet Without Wind. Aluminum Cable.

Rise above minimum temperature F°.	200 Foot Span.			400 Foot Span.			600 Foot Span.			800 Foot Span.			1,000 Foot Span.		
	553,150 CM.	265,400 CM	132,300 CM.	553,150 CM.	265,400 CM.	132,300 CM.	553,150 CM.	265,400 CM.	132,300 CM.	553,150 CM.	265,400 CM.	132,300 CM.	553,150 CM.	265,400 CM.	132,300 CM.
0°	.42	.45	.46	1.80	1.95	2.20	4.3	5.1	6.2	83.6	10.3	14 0	13.9	18.6	26.0
20°	.51	.52	.55	2.20	2 42	2.75	5.1	6.1	7.2	9.5	11 7	15 4	15 6	20 3	27.6
40°	65	.65	.69	2 70	2.90	3.40	6 0	7.1	8.4	10.8	13 2	16 9	17.3	22.0	29.0
60°	.83	.85	.92	3.35	3.70	4.20	7.0	8.2	9.7	12 3	14.7	18 3	19 1	23.8	30.5
80°	1 07	1 13	1.30	4.15	4 50	5.10	8.2	9.5	11.0	13 8	16.4	19.6	20.8	25.5	31.8
100°	1.57	1.65	1.82	5 05	5 45	6 00	9.5	10.8	12 2	15.4	17.7	20.9	22 5	27 1	33 1
120°	2 20	2 27	2 45	6.00	6.40	7.00	10.8	12 0	13.3	16.9	19.1	22 2	24.2	28.6	34.4
140°	2 75	2 80	2.95	6 90	7 35	7.85	11.9	13.1	14.4	18.3	20 4	23.4	25.9	30 0	35 8
150°	2.97	3 03	3 10	7.20	7.78	8 50	12.5	13.6	15.7	19.0	21 5	25.5	26 7	31.5	37.5

Wire stressed to elastic limit at minimum temperature with 65 miles per hour actual wind velocity.

TABLE IV.—DEFLECTIONS OF ALUMINUM WIRE WITHOUT WIND. DEFLECTIONS IN INCHES. MAXIMUM TENSION 14,000 POUNDS PER SQUARE INCH AT MINIMUM TEMPERATURE WITH WIND 65 MILES PER HOUR ACTUAL VELOCITY.

RISE ABOVE MINIMUM TEMPERATURE F°	LENGTH OF SPAN.					
	200 ft.	180 ft.	160 ft.	140 ft.	120 ft.	100 ft.
0	6 30	5 30	4.20	3.10	2.20	1.70
10	7 00	5.70	4.50	3.40	2.40	1.75
20	7 80	6 40	5 10	3.80	2.80	1 90
30	8.80	7.25	5.75	4.50	3.20	2.20
40	10 20	8.40	6.70	5.20	3 80	2 70
50	12.00	9 80	7.80	6.40	4 60	3.30
60	14 00	11.50	9 40	7.50	5.60	4.00
70	16 50	14 00	11.50	9.20	7.00	5.20
80	19 75	17.00	14.25	11.40	8.90	6 80
90	23 10	20.00	16.80	13 80	10.30	8.75
100	26.60	23.30	20 00	16.60	13.10	10.80
110	29.75	26 60	23.00	19 50	16 25	13.10
120	33 45	29.75	25.75	22.20	18.70	15.20
130	36 75	32 80	28.70	24.50	20.80	17.20
140	40 00	35.75	31.50	26.80	22.80	18.80
150	43.00	38.40	33 60	29.10	24.80	20.30

Calculations made for No. 2 B & S stranded conductor.

APPENDIX.

The method used in the calculation of the curves in Figs. 2, 3, 4 and 5 is a graphical one based upon the Catenary formulae in Weisbachs' Mechanics. The method is exemplified here in detail, in order to show the relations of the various elements of the problem:

1). $x = \dfrac{y^2 w}{2T}$

Where x = deflection at the center of the span in feet.

y = one-half the length of the span in feet.

w = weight per foot of wire in pounds, or the resultant of wind and weight if wind pressure is taken into consideration.

T = tension in wire at center of span in pounds.

2). $l = y\left[1 + \frac{2}{3}\left(\frac{x}{y}\right)^2\right]$

Where l = one-half the length of wire in the span.

3). $x = \dfrac{\sqrt{3yl - 3y^2}}{2}$

The following formulae were also used which explain themselves:

4). $\dfrac{T L}{M a} = E$

Where E = the elongation of a wire in feet within its elastic limit under a tension T; where M = modulus of elasticity, a = sectional area of wire in square inches, and L = length of wire in span in feet.

5). $L_m = L_o (1 + KM)$.

Where L_m = length of a wire at maximum temperature.

L_o = length of wire at initial temperature.

K = coefficient of linear expansion.

M = Maximum rise in temperature in degrees F.

Example.

In a 1,000-foot span, to find the deflection at maximum temperature with the wire strung in such a way that at minimum temperature with a wind velocity of 65 miles per hour (actual) the wire will be stressed to its elastic limit.

Assume 500,000 cm aluminum diameter = 0.81 in.; weight per foot = 0.46 lbs.; area = 0.393 sq. in.; modulus of elasticity = 9,000,000; elastic limit of wire = 5,500 lbs.; rise in temperature = 150 deg. F.; wind pressure (from curve) = 10.6 per sq. ft. = 0.716 lbs. per ft. of cable; resultant of wind and weight = 0.85 lbs. per ft. of cable.

From equation (1)—

$$x = \frac{500^2 \times .85}{2 \times 5{,}500} = \frac{212{,}500}{11{,}000} = 19.3 \text{ ft.}$$

which will be the deflection of the wire under wind pressure at minimum temperature in a plane which will, of course, be deflected from the vertical, the tension being the elastic limit or 5,500 lbs. The length of the wire under these conditions can be found from equation (2)—

$$l = 500\left(1 + \frac{2}{3}\left(\frac{19.3}{500}\right)^2\right) = 500 + \frac{1{,}000 \times 372}{750{,}000} = 500.496$$

$$2l = L = 1{,}000.992 \text{ ft.}$$

Next assume that the wind has ceased and that hypothetically the weight of the wire has been reduced to an infinitely small quantity. The wire then will not be stressed and it will contract elastically to a position of zero extension. This contraction can be found from equation (4)—

$$E = \frac{5{,}500 \times 1{,}000.992}{9{,}000{,}000 \times .392} = 1.56 \textit{ ft.}$$

Length of wire unstressed will then be at minimum temperature $1{,}000.992 - 1.56 = 999.432$ ft.

Next assume the temperature to rise 150 deg. F. The wire will then expand an amount shown in equation (5)—

$$L_m = 999.432\ (1 + .000{,}012{,}8 \times 150) = 1.92 \text{ ft.}$$

Length unstressed then at maximum temperature will be 999.432 + 1.92 = 1,001.352 ft., which corresponds to a deflection [from equation (3)] of 22.5 ft.

Next assume, hypothetically, that the wire has its normal weight restored. It will then sag down from the above deflection until such a new deflection is reached that the tendency to elongate due to gravity stress is just balanced by the elastic tendency to contract. This will be the deflection sought for in this problem. It can be found graphically as follows:

Starting with the deflection at maximum temperature and zero tension (22.5 ft.) assume certain increasing tensions in the wire and find the corresponding deflections by applying equation (4), to get the increased length and equation (3) which will give the corresponding deflection. Plot these tensions and deflections (Fig.

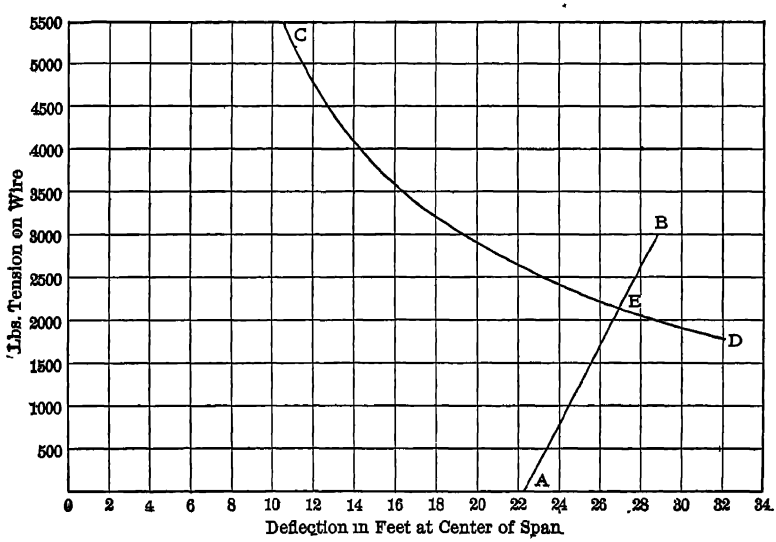


FIG. 6.

6) which gives the curve AB. This curve represents the relation between tension and resulting deflection in the wire as the wire sags down under gravity stress from its hypothetical position of zero tension. Next plot a curve CD (Fig. 6) by substituting vari-

ous values for T in equation (1) where $W =$ the weight of the wire per foot.

This curve shows the relation between tension and deflection in the wires at various tensions when it is assumed to have its normal weight per foot.

The point of intersection E of these two curves is the point of equilibrium and the deflection corresponding to this point (27 ft.) is the deflection in question. It is the point where the force of elastic contraction is balanced by the gravity stress.

This problem can be solved analytically by a number of methods, but the process leads to complex cubic equations, and a graphical method brings out more clearly the physical relations in the proposition. For this reason it is given here in detail.

Chairman SCOTT: A second paper bearing upon the same general subject is that of Mr. Blackwell on "Conductors for Long Spans." Mr. Blackwell was here the first of the week but could not be here to-day.

At the request of the Chairman, Mr. Lincoln then read Mr. Blackwell's paper.

CONDUCTORS FOR LONG SPANS.

BY FRANCIS O. BLACKWELL.

As electric power is transmitted over greater distances and transmission plants grow in size, more attention must be given to the importance of improving the construction of transmission lines.

A very large number of transmissions of from 50 to 150 miles are now in operation, many of them with several main circuits radiating from a common power center, with other lines in turn branching from these main circuits. The territory covered by such plants is so great, and the transmission system so complex, as to call for a departure from the earlier methods developed from telegraph and telephone practice.

It is obvious that the longer the line the more reliable and substantial it must be. A plant transmitting power five miles might be shut down three or four times a year by line troubles without seriously interfering with its service. If, however, there were 500 miles of circuits instead of five, and the same number of accidents per mile occurred, the plant would be shut down every day and the power would be absolutely valueless. Moreover, the longer the transmission line the more difficult it is to locate and correct a fault. On a five-mile line repairs might be made in an hour or two while on a 500-mile system it would probably take a day to find the place and get the plant in operation again.

Existing wooden pole lines have given good results and electric power has proved successful even under adverse conditions and justified the investment of greater capital in larger plants and longer power transmissions.

The same reasons which have led the railroads to replace their wooden bridges with steel structures will ultimately cause power transmission engineers to substitute steel for wood in all important transmission enterprises. The advantages of a steel-tower construction are that it is fireproof, durable and readily admits of structures of a size and strength impracticable with wood. With

higher and stronger supports for the power circuits longer spans can be employed and the number of points of support correspondingly reduced. This fewer number of parts much simplifies the transmission system, both in construction and in operation, and permits of more expensive and reliable designs being used. The wires may be placed much farther apart thus obviating the principal cause of trouble — short-circuits. The insulators may also be larger and better, both electrically and mechanically, and every part of the system can be laid out in advance, the strains calculated and the structures designed with ample factors of safety.

The length of span to use is the most difficult question and the one into which the most factors enter. The calculation of long spans is primarily a suspension-bridge problem in which all the mechanical stresses must be fully investigated.

The strength of the conductor is at least as important as its conductivity and the purpose of this paper is to give the results of investigations, made under the direction of the writer, to determine the characteristics of conductors so as to secure some definite basis upon which to figure long spans. To this has been added other data which must be assumed and the method of calculation followed.

The materials available as conductors are copper, aluminum, iron and steel. The alloys of copper and aluminum have strength but low conductivity and have not been considered in this paper.

Copper Wire.

Copper wire varies widely in its characteristics depending on the methods used in its manufacture. The copper is received at the wire mill in the form of cast-wire bars weighing 200 to 300 lbs. It is then rolled into rods and the rods are drawn into wire of the required size. The temperature at which the metal is rolled, the reduction of area both in rolling and drawing, and the amount of annealing which the wire is given, all have an important bearing on its characteristics. As the size of the original wire bar is limited, the smaller the wire, the more it is worked and in general the better the result.

Fig. 1 shows stress and strain curves of different kinds of copper wire, made in a Riehlé tension machine, which are plotted in terms of pounds per sq. in. and per cent elongation in 60 ins., so that the different wires, although of various sizes, can be directly compared.

A is soft annealed wire of .168″ diameter; *B* is ordinary half hard wire of .363″ diameter; *C* is hard trolley wire of .363″ diameter; and *D* is hard-drawn telephone wire of .1046″ diameter.

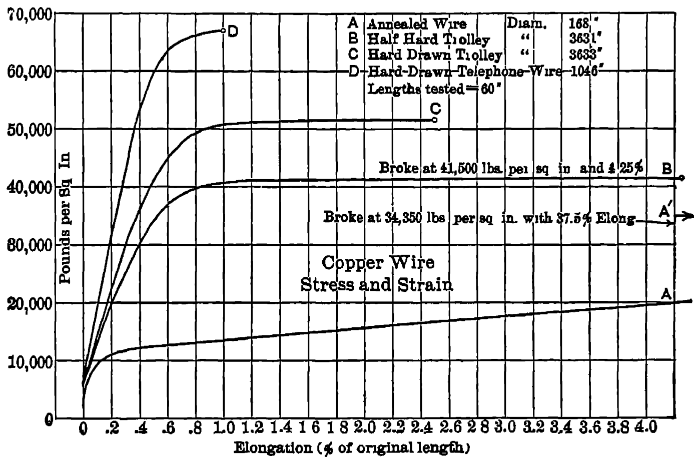


FIG. 1.

It will be noted that the ultimate resistance of these wires varies from 34,350 lbs. to 67,000 lbs. per sq. in., and the elastic limit, which is assumed to be at the point where the stress and strain cease

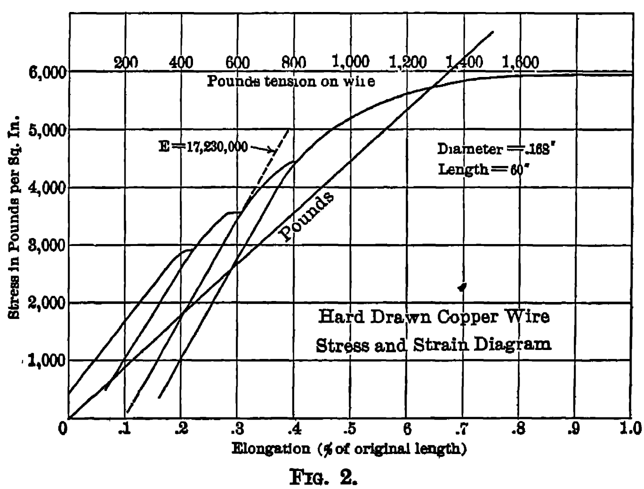


FIG. 2.

to be proportional (the tangent point of the curve), varies from 7000 lbs. to 40,000 lbs. per sq. in. In these curves the read-

ings were made as quickly as possible to prevent the wire taking a set.

In Fig. 2 is shown a diagram of .168″ diameter hard-drawn copper wire in which the wire is given time to take a set at certain points. The curve is repeated several times by running up from zero to a higher stress than before, and it will be noted that the wire takes a permanent set at each stress to which it is subjected, and the longer the time the greater the set.

Fig. 3 shows the curve of the same .168″ diameter wire given on Fig. 2 that had already been broken in the testing machine at

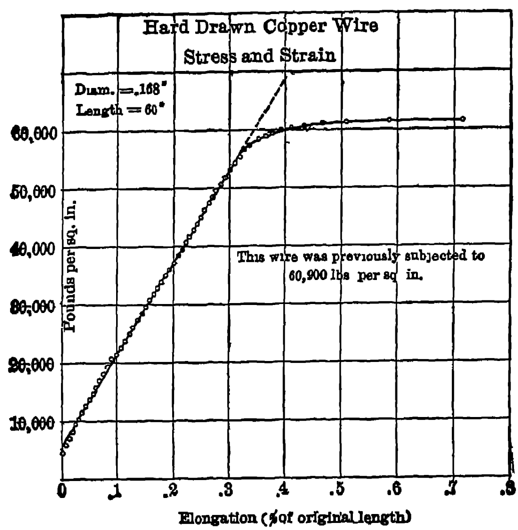


FIG. 3.

60,900 lbs. per sq. in. and consequently had taken the maximum set. In this case the elastic limit, taken at the tangent point of the curve, would be 55,000 lbs. per sq. in., instead of the 35,000 lbs. it had originally, as shown in Curve *D* in Fig. 1. It is evident, therefore, that the actual elastic limit can be made nearer the ultimate resistance by stretching the wire either in drawing it or afterward.

In order to study the effect of time upon the elongation of wire, and to determine whether the wire would continue to stretch and ultimately break at points below the elastic limit, the arrangement shown in Fig. 4 was devised. This consists of jaws to clamp the

ends of the wire so that a weight can be suspended by it. In order to measure the elongation, the copper wire is passed through a

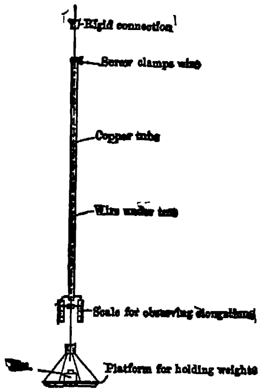


FIG. 4.

copper tube which is clamped to the wire at the upper end. As the tube and wire are of the same material the elongation can be

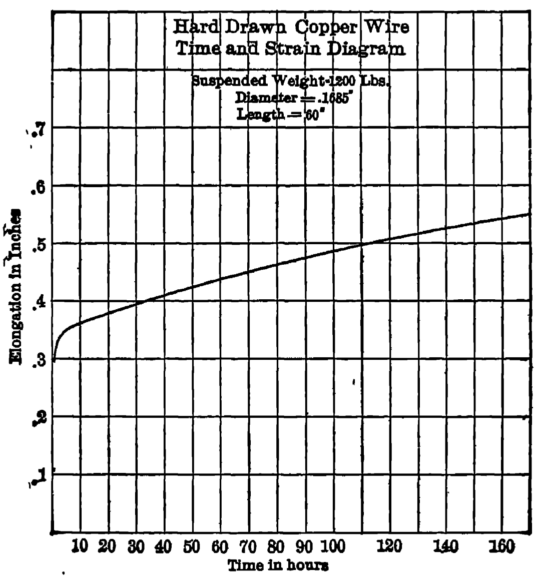


FIG. 5.

measured independently of the changes in the temperature of the room. The wire was then subjected to a stress and the elongation measured at different times.

Fig. 5 is a curve of strain and time upon a 5-ft. piece of the .168″ diameter copper wire which was subjected to a stress of 1200 lbs. or 54,000 lbs. per sq. in. for seven days, eight hours, until it broke. This shows that a wire will not stand continuously 90 per cent of its ultimate resistance as pieces of this wire broke again in the testing machine at 61,000 lbs. per sq. in. The elongation shown by the weight test was not materially different from that given by the testing machine in Fig. 5. So far as these suspension tests have gone they indicate that hard-drawn copper wire, which has an elastic limit of 40,000 lbs. per square inch as ordinarily

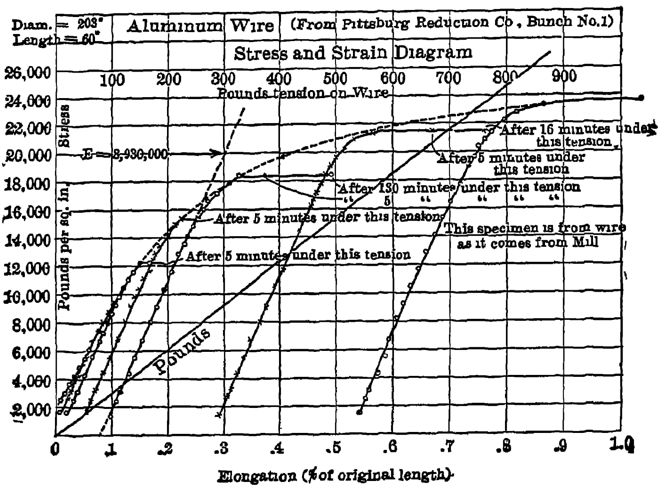


FIG. 6.

tested, will stand continuously about 50,000 lbs. per sq. in., or 80 per cent of its ultimate strength.

ALUMINUM WIRE.

The conditions of manufacture have the same effect upon the characteristics of aluminum as in the case of copper wire. The elongation of hard-drawn aluminum averages about the same as that of hard-drawn copper in the samples tested and the aluminum wire takes a set in the same way as already mentioned in copper.

Fig. 6 is a curve upon aluminum wire of .2037″ diameter taken with time intervals to allow the wire to set. The ultimate resistance of the aluminum wire tested averaged about 24,000 lbs. per sq. in., and the elastic limit from 12,000 to 14,000 lbs. This aluminum wire gave 60 per cent of the conductivity of hard-drawn copper

of equal cross-section. The cross-section for equal conductivity must, therefore, be 60 per cent greater than that of copper and the diameter 27 per cent greater. The weight, on the other hand, is about one-half that of copper for equal conductivity.

Iron and Steel Wire.

Fig. 7 shows the stress and strain diagram of common soft .1638″ diameter galvanized iron telegraph wire. Its resistance was 7.4 times that of copper. The ultimate resistance and elastic limit of this wire are less than that of hard-drawn copper wire.

The elongation (11 per cent), however, is much greater, showing that the iron wire gets its strength from the material rather than from the method of manufacture. It probably was stronger before

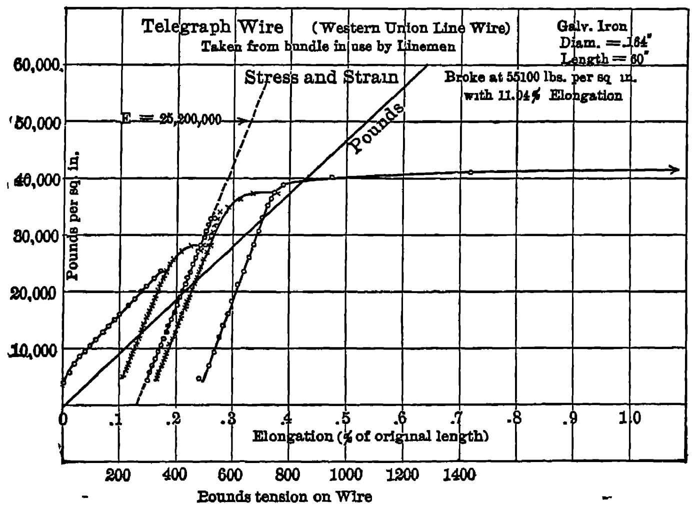


Fig. 7.

it was galvanized which, undoubtedly, drew the temper and reduced the strength.

Tests upon samples of steel wire, made before and after galvanizing, showed that the ultimate resistance was 43 per cent higher before being galvanized and the elongation one-tenth. Iron and steel take a set under stress the same as the copper and aluminum samples.

Figs. 8 and 9 show curves of galvanized crucible steel .109″ diameter wire made by the American Steel & Wire Company, which had an ultimate resistance of nearly 230,000 lbs. per sq. in.,

and an elastic limit of about 125,000 lbs. per sq. in. This wire takes a set similar to that shown by other materials. The

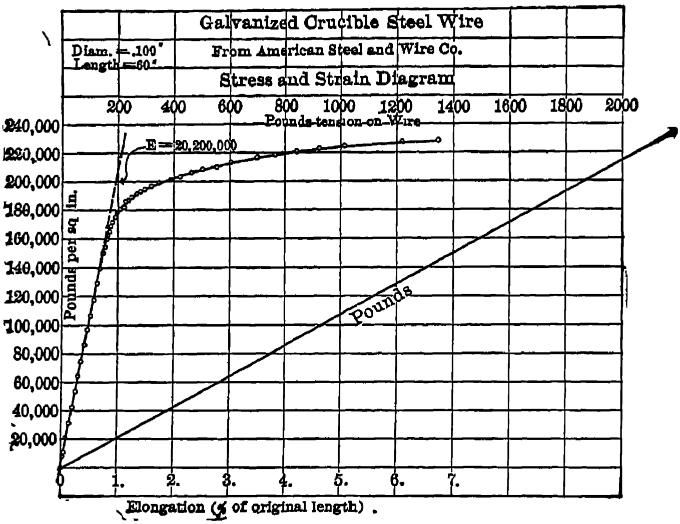


Fig. 8.

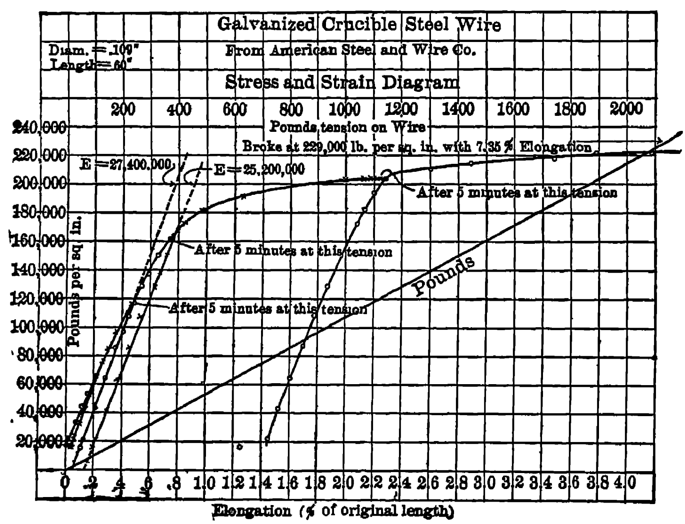


Fig. 9.

elongation is noticeably greater than that of copper. The resistance of this wire was 11.6 times that of copper of equal cross-section.

The diameters of these iron and steel wires would, therefore, be from 2.7 to 3.4 times those of copper of equal conductivity.

CABLES.

Copper cable made up of several strands has the advantage of using smaller wires than a solid conductor and also permits of longer lengths of conductor without splices. Assuming a 300-lb. wire bar, a 19-strand cable for example can be made up weighing 5700 lbs. while if solid wire were used the weight of one piece would be 300 lbs. In other words, there would be 19 times as many joints with the solid wire as with the 19-strand cable. The smaller

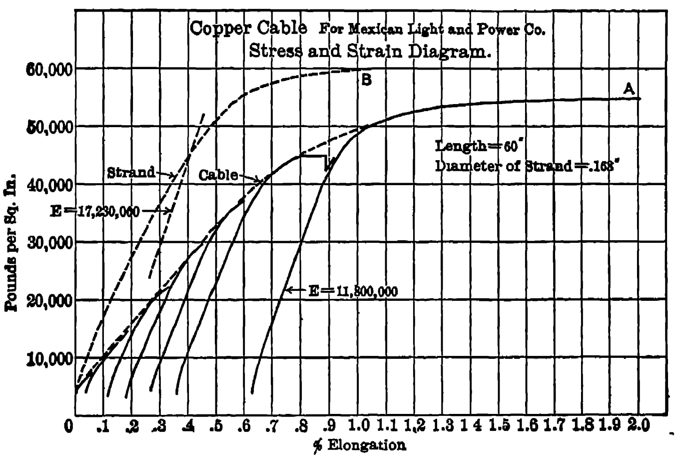


FIG. 10.

the wire and the greater the strength the more brittle it becomes. This is partially compensated for by the greater flexibility of a cable and the fact that a strand can break without the whole conductor parting.

Each strand should be a continuous wire without joints. Joints in the cable should be as few as possible and made by means of twisted sleeves, as brazing or soldering anneals the wire and much reduces its strength.

In Fig. 10, *A* is the curve of a copper cable made up of 6-strand .168-in. diameter wire on a hemp center with three and one-half twists per foot. *B* on the same sheet is the diagram of one of the strands of which this cable is composed. It will be noted that the

cable had but 90 per cent of the strength of the strand but a much higher elasticity and elongation.

The center wire of seven strand cables broke before the outer strands showing that it takes the strain before the other strands on account of its less elasticity. The outer strands are longer and to a limited extent may be considered as spiral springs. It will be noted that the cable is more elastic than the solid strand which is a desirable characteristic in long spans, as will be shown later.

Fig. 11 shows the curve of a galvanized seven-strand crucible steel cable similar to the strands shown in Figs. 9 and 10.

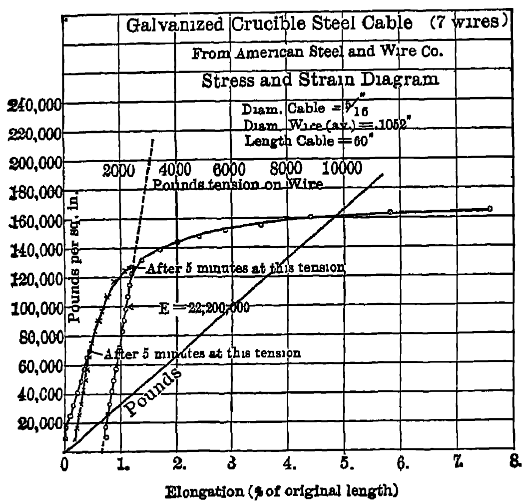


Fig. 11.

It will be noted that the strength of the cable is but three-quarters of that of the strands.

The most serious objection to the use of iron or steel wire is that the galvanizing only protects the wire for a few years and it is, therefore, less permanent than copper.

Elasticity.

The elasticity of the conductor is of considerable value in reducing the sag when the stress is removed. The elongation of the wire under stress is less after it has once been stretched. The elasticity of cable is greater than that of solid wire, but both wire and

cable take a set under any stress to which they may be subjected. In the following table is given the average modulus of elasticity found for copper, aluminum, iron and steel wire and cable:

Copper hard-drawn wire	16,000,000
Copper hard-drawn cable	12,000,000
Aluminum hard-drawn wire	10,000,000
Aluminum hard-drawn cable	7,500,000
Iron galvanized wire	24,000,000
Steel galvanized wire	27,000,000
Iron and steel cable	22,000,000

Each sample was stretched to a point somewhat below its elastic limit before testing. It will be noted that cable is considerably more elastic than the solid wire. The stress and strain diagrams show this. Aluminum is considerably more elastic and has a decided advantage over copper in this respect. Iron and steel are less elastic than either copper or aluminum.

Coefficients of Expansion.

The coefficients of expansion for Fahrenheit degrees are as follows:

Copper	0.000,009,6
Aluminum	0.000,012,8
Steel	0.000,006,4

As the worst condition, so far as sag is concerned, is reached when the conductor is hot, a low temperature expansion is most desirable for long spans, and steel is in this respect better than either copper or aluminum.

Weight of Conductors.

The relative weight of conductors of different metals for equal conductivity of course depends upon their conductivity for equal cross-section and their specific gravity.

Iron and steel weigh about 86 per cent and aluminum 30 per cent as much as copper of equal cross-section.

The electrical resistance of iron and steel varies from 7 to 12 times, and that of aluminum is 60 per cent more than that of copper. In order to obtain any given conductivity it is necessary to pur-

chase from 6 to 11 times as much iron or steel and but one-half as much aluminum. At present prices of wire, copper is cheaper than iron or steel. If other things besides weight were equal, aluminum would be the best conductor for long spans, as its tensile strength for equal weight is greater than that of copper or iron wire, but less than that of steel. In addition to carrying its own weight, a conductor must also in a cold climate be able to bear the ice which may accumulate upon it in sleet storms.

The writer has assumed that from 1/2 to 1 in. of ice may cover the surface of the wire. In addition, the effect of wind must be considered, not only upon the conductor alone but also on the ice which may be on the wire. Where a large amount of power is being transmitted considerable energy is dissipated in the conductor and the temperature of the wire will be kept above that of the atmosphere and sleet will not form on the conductor.

Wind Pressure.

The greatest stress in the wire is caused by wind pressure. This is generally assumed in engineering structures to be 40 lbs. to 50 lbs. per sq. ft. or flat surface with a wind velocity of 100 miles per hour. Forty pounds is undoubtedly ample to allow for, as higher pressures are only obtained on limited areas and the average pressure on a long span would be much less than the maximum. It is also improbable that the highest wind would be exactly at right angles to the line. Ice on the wire will also break off more or less with high winds. Small conductors suffer more from wind and sleet than larger ones, as the exposed surface varies directly as the diameter, while the cross-section and, consequently, the strength increases as the square of the diameter. A given thickness of ice on a wire is evidently a heavier load on a small than on a large wire. It is, therefore, most undesirable to employ small conductors for power transmission. On a cylindrical surface a given wind velocity only causes half the pressure that it does on a flat surface, so that the maximum pressure on a conductor can be taken at 20 lbs. per sq. ft. The less the diameter of a conductor for a given conductivity the better, so far as wind strains are concerned.

As aluminum wire must be 27 per cent greater in diameter and iron and steel from 2.5 to 3.5 times the diameter of copper, they compare unfavorably with the latter in this respect.

Span and Sag.

In calculating the sag in a conductor for any span, the maximum stress which can be permitted in the wire must first be assumed. This should be the elastic limit of the wire with a factor of safety. The maximum side strain per foot of conductor is the resultant of the weight and wind pressure which are at right angles to each other. If there is sleet, the weight of the ice and the wind effect upon the increased diameter of wire due to ice must be allowed for.

The maximum sag may be due to the conductor being loaded with sleet or to heating of the wire in a hot sun. The latter will generally be found to give the greater sag. Owing to the conductor being elastic, it is not necessary to consider the greatest deflection

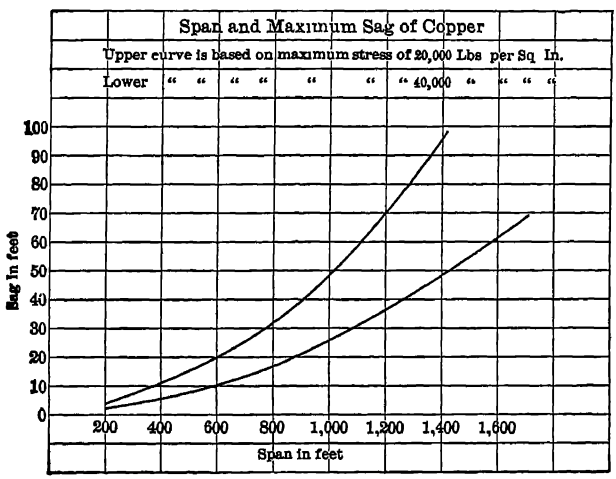


Fig. 12.

from a horizontal line between supports as the vertical sag of the wire. The wind pressure causes the wire to swing to one side, and it is elongated by the combined strain of wind and weight; but as soon as it is relieved of the wind pressure it swings back to a vertical position and contracts to the length required to carry its weight alone. The sag due to heating of the wire is also somewhat less than it otherwise would be, because when expanded the strain is less and the wire contracts.

The extreme variation of temperature of the air in cold climates is about 150 deg. F., while further south it does not exceed 100 deg. F. To this must be added something for a conductor exposed

to a hot sun. There is no data upon this, but a total variation in the temperature of the conductor of 175 deg. F. should be sufficient in any country.

Curves of Span and Sag.

The attached curves of span and sag are taken from a paper presented by the writer before the American Institute of Electrical Engineers on June 22, 1904, as are also the following calculations:

The curves in Figs. 12 and 13 show the span and maximum sag of copper and aluminum cables at the elastic limit and also at one-half the elastic limit. They do not allow for ice on the wires

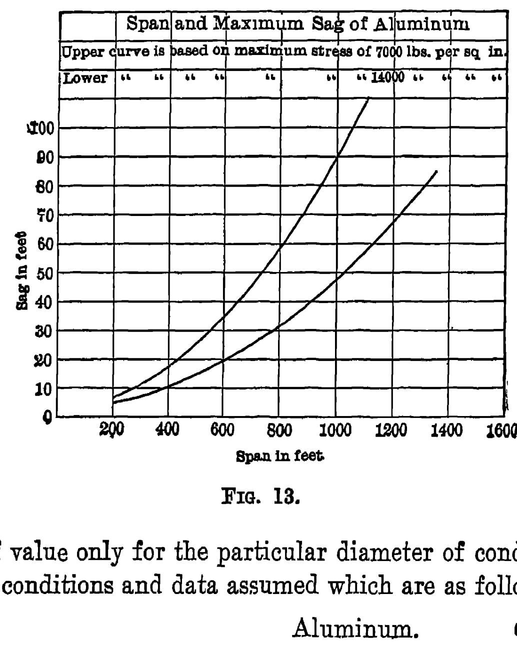


Fig. 13.

and are of value only for the particular diameter of conductor, and under the conditions and data assumed which are as follows:

	Aluminum.	Copper.
Area 6-strand cable	0.21 sq. in.	0.132 sq. in.
Diameter 6-strand cable........	0.59 in.	0.51 in.
Weight per foot	0.240 lb.	0.509 lb.
Elastic limit	14,000 lb.	40,000 lb.
Stress at 1/2 elastic limit	1470 lb.	2640 lb.
Stress at elastic limit	2940 lb.	5280 lb.
Wind pressure per sq. ft............	40 lb.	40 lb.
Wind pressure per ft. cable.........	0.98 lb.	0.84 lb.

Coefficient of expansion	0.000,013	0.000,009,6
Variation in temperature	150° F.	150° F.
Modulus of elasticity	8,000,000	16,000,000

The equations from which the curves were calculated are given below and alongside of them is an example of a 1000-ft. copper span.

$$D = \frac{S^2 \times W}{8\,T} = \frac{1000^2 \times 0.98}{8 \times 2640} = 46.4 \text{ ft.}$$

In which D = deflection in ft.
S = span in ft.
W = resultant of weight and wind in lb. per ft. of cable.
and T = stress allowed in cable in lbs.

$$L = S + \frac{8\,D^2}{3\,S} = 1000 + \frac{8 \times 46.4^2}{3 \times 1000} = 1005.74 \text{ ft.}$$

In which L = length of cable, cold.

$$L_0 = \frac{L}{1 + \frac{F}{E}} = \frac{1005.74}{1 + \frac{20,000}{16,000,000}} = 1004.38 \text{ ft.}$$

In which L_0 = length of cable without stress,
F = lb. per sq. in. permitted in cable,
and E = modulus of elasticity.

$$L_H = L_0(1 + C\,B) = 1004.38\ (1 + 0.000,000,9 \times 150) = 1005.81 \text{ ft.}$$

In which L_H = length of cable, hot (150 deg. F. rise in temperature),
C = coefficient of expansion,
and B = maximum degrees F. rise in temperature.

$$D^3 + \frac{3\,S}{8}\,(S - L_H)\,D = \frac{3\,S^3\,L_H\,W}{64\,E\,A}$$

$$D^3 + \frac{3 \times 1000}{8}(1000 - 1005.81)\,D = \frac{3 \times 1000^3 \times 1005.81\ W}{64 \times 16,000,000 \times 0.132}$$

$$D^3 - 2178.7\,D = 22,323\ W.$$

In which A = area of cable.

From this equation any deflection of the cable can be assumed and the corresponding weight calculated. For instance, in the example if $D = 48.8$ ft., $W = 0.51$ lb.; that is the sag hot, without wind, is 48.8 ft., which is the maximum vertical deflection under the conditions assumed.

If $D = 51.1$ ft., $W = 0.98$ lb. which is the maximum deflection with wind but this is at an angle of 31 deg. from the horizontal and the vertical sag is only 26.6 ft.

DISCUSSION.

Chairman SCOTT: We are fortunate in having with us Mr. Robert Kaye Gray, President of the British Institution of Electrical Engineers, and as I believe this is in his professional line, we will be very pleased to have him open the discussion.

President GRAY: Well, gentlemen, in talking about the conductors and the use of aluminum, we have, as you are all aware, not very much experience in England, but after hearing what Mr. Buck has said, I think that there is one point of very considerable interest and that is with respect to the joint. I understood he is employing the stranded cable, but I did not catch very clearly the manner in which the two ends were lined and joined together. Is the strand a 7-strand or a 19-strand? And do you make a long splice? I do not want to ask anything that you do not feel at liberty to tell us.

Mr. BUCK: It is a 19-strand. Each strand is wound around the core separately.

President GRAY: I am very much obliged to Mr. Buck for this information. Your description has been exceedingly clear, and I cannot add anything to the discussion.

Chairman SCOTT: Mr. Buck's paper is valuable for two points. One is the comprehensive statement he has given regarding the characteristics and use of aluminum conductors; the second is the valuable data which he has given from the beautiful and extensive tests which he has made. I regard his contribution as one of very considerable engineering value. He has set an excellent example in taking this problem, which has been so much discussed, and evolving a very simple and direct way of getting the very valuable data which are required. We have with us this morning, in addition, gentlemen who are connected with the manufacture of aluminum and aluminum wire, and engineers who have been using aluminum conductors in their work in the West; also other engineers who have given the matter general consideration.

Mr. P. N. NUNN: It seems to be generally understood that the deflections of aluminum conductors are greater than those of copper. This is not usually true. While the coefficient of expansion of aluminum is greater than that of copper, so also is its elasticity, and these two factors of deflection work oppositely. Moreover, the difference in elasticity is greater than that in expansion. If the commercial aluminum wire now used, and medium drawn copper, be erected sufficiently tight so that at minimum temperature the respective tensions slightly exceed the elastic limits, then the conductors will slightly "draw" without apparent injury, and minimum feasible deflections will at all times be secured. A range of temperature greater than 120° or 130°F. is seldom found at more than a few successive spans. Under these conditions, the deflections of aluminum in even short spans, at moderate temperatures, will be less than those of copper, while in spans of over 200 feet, they will be less at all temperatures.

Mr. BUCK: In regard to the question of taking into consideration the modulus of electricity and the coefficient of expansion, I want to say that they were both included in these calculations, and if we have any confidence in mathematics, there is no reason to doubt that the deflection of aluminum will be greater than for copper at the hypothetical high tem-

perature of 150° Fahrenheit. If you do not include wind pressure, aluminum starts with a very much lower initial deflection at minimum temperatures; but as the temperature rises, the aluminum overtakes the copper and passes it; so that at the highest temperature the deflection is considerably more.

Mr. P. M. LINCOLN: I think possibly there is one element which has not been taken into consideration in either Mr. Nunn's discussion or Mr. Buck's, and that is that the supports in any transmission line are not absolutely rigid; they are flexible to a considerable extent; and as the tension decreases by elevation of temperature, this elasticity of the supports will come in and take up a considerable portion of the sag which would otherwise occur. That possibly may be the reason for Mr. Nunn having noted a smaller sag with aluminum than with copper. There is one question which I would like to ask in regard to Mr. Buck's paper, and that is what causes this difference between indicated wind velocities and actual wind velocities? I did not realize that such a large difference obtained.

Mr. BUCK: The Government anemometer, as you know, is made of a series of cups. One side of each cup is convex and the other concave. The concave side offers more resistance than the convex; so that the anemometer rotates in that direction. At low wind velocities the relation between those two resistances has a certain value. As the wind velocity increases, that relation changes; so that the anemometer rotates faster, relatively, at high wind velocities than it does at low velocities and the correction factor increases. Why it does is a physical matter, that I will not venture to explain.

Mr. R. S. HUTTON: About everything that Mr. Buck has brought out we find quite true out on the Coast. Of late we have been going to the long-span proposition. Most of our transmission lines run through a mountainous country and we cross some very deep gulleys. These have given us excellent opportunities to try long spans, and we have some, of aluminum wire, as great as 1800 feet. At first it was thought that we would have to give the wires very great separation. We started in, however, with a medium spread of wires, and found that during the wind storms, owing to the great weight of these spans, and the low periodicity of the natural vibration, they all swing together, so that they are practically parallel at all times. It therefore appears that there is very little possibility of their ever crossing in a wind storm, and we have yet to experience a single case where any of our long spans have ever crossed in a wind storm, and we have had some as high as 72 miles an hour, according to the records of the Weather Bureau.

Chairman SCOTT: The element in a transmission line which is next in importance to the conductor, is the insulator. There is probably no element in the general branch of high-tension transmission upon which more is involved, and upon which more depends and, on the other hand, to which more attention has been given and a greater variety of product has been produced than in high-tension insulators. One of the men who has had to do with high-tension work in some of the earliest and most important high-tension plants and has made a special study of the insulator, is Mr. Converse, who will now present a paper on that subject.

HIGH-TENSION INSULATORS.

BY V. G. CONVERSE.

It is only 14 years since 3,000 volts was considered a very high tension, and the success of a transmission at this tension was looked upon with far more skepticism than we attach to one of 80,000 volts at the present time. As the steps in high tension have been made with the increasing use of alternating currents, and as alternating-current power transmission dates back but the 14 years mentioned, the province of this paper may then be considered to be within these limits.

It is a little difficult to trace the early stages in the development of the high-tension insulator. Undoubtedly the first forms were copied from insulators used for telegraph and telephone work. Certain it is that the same styles of insulators were proposed, and the same theories were advanced. As the tension or voltage increased, the insulators were made larger and had various petticoats in order to prevent the leakage of current. Since it was found in telegraph work that if the surface of the material of the insulators was hygroscopic there was difficulty in transmitting the message, the materials of high-tension insulators were very carefully considered, in order that this dangerous hygroscopic condition might not so reduce the effectiveness of the insulator that vital quantities of current would leak over the surface. The same constructions for cross-arms, pins, and the securing of insulators, adopted by the telegraph and telephone companies, were appropriated for power transmissions, and until a few years ago the aim has been to use such details of construction as had become standard and thus could be easily obtained.

Glass and porcelain are the only materials which have been used extensively for high-tension insulators, although many other materials and compositions have been proposed and tried. At times it has seemed as if one possessed qualities of decided advantage over the other, but a better understanding of the requirements, or an improvement in the method of manufacture, has brought

the other to an apparently equal basis, so that from the first we have had glass insulators and porcelain insulators, and even combinations of glass and porcelain.

The commercial success of high-tension transmissions having been until late years in doubt, developments of insulators have been in the improvement in form and materials, no radical changes in construction being ventured, yet every engineer has had his own ideas regarding the details of construction. It would seem as if almost every engineer who has had the opportunity of exploiting his ideas has done so. As a result, we have had at various times insulators with gutters and spouts, insulators in the form of helmets, some with drip points, and others with every conceivable form and combination of petticoats. The situation has been further complicated by a variety of ties for securing the line to the insulator, pins of wood and of iron, various threads for securing the insulator to the pin, and even by a wide range of colors of material. It is little wonder that the manufacturer of porcelain or glass who was skilled in the art of making table-ware and various other utensils, and perhaps telegraph insulators, has hesitated when confronted by the requirements of the up-to-date high-tension engineer.

Now it should be stated to the credit of the manufacturer that the arts of making porcelain and glass, which have descended to us from periods antedating the Christian era, had reached a certain stage of perfection. Strong and beautiful and satisfactory wares were made, but here was a new requirement. The material of the insulators must be strong to withstand mechanical strains, and it must also withstand the unseen and unknown electrical forces which tend to break it and render the insulators useless. The improvements which have been made in glass have been in the direction of strengthening the quality in order to protect against mechanical breakage, the structure of glass already suiting electrical conditions very well. The improvements in porcelain, which have been in the direction of strengthening the body of the material to resist electrical puncture, have been interesting and are noteworthy. From porcelains, which were first furnished for insulators and would stand but a few thousand volts —perhaps these few thousand volts going farther through the body of the porcelain than if no material whatever were interposed— the advance has been in the line of obtaining a more homogeneous, refractory and vitreous grade of material which is strong in resisting electrical breakage. Of recent years the combining

of layers of this high-grade electrical porcelain has further strengthened the body of the insulator.

But let us trace directly the forms of insulators which have been used. In 1890, the first alternating-current power transmission in the United States used for 3,000 volts a glass insulator of the form shown in Fig. 1. This is an insulator such as is

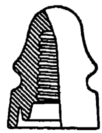


FIG. 1. TELEGRAPH INSULATOR.

commonly used by the telegraph companies, and is only about 3 in. in diameter. In spite of the predictions that the insulator would not suffice, the plant continued in operation for six years without insulator troubles.

For the famous Frankfort-Lauffen transmission experiments in Germany in 1891, a porcelain insulator with an oil cup was used. No definite information as to the exact shape of this insulator is at hand, but the principle was probably not unlike that of the insulator shown in Fig. 2. Voltages as high as 28,000 to 30,000

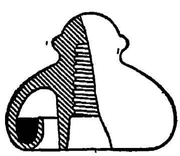


FIG. 2. OIL CUP INSULATOR.

were used in these experiments for a limited time. Insulators with oil cups of various forms appeared very shortly afterwards in England and the United States. If the insulator was of glass, the outer petticoat was usually curved inward and up, so as to form an internal groove which would hold oil. A common form for porcelain insulators was to bring down a petticoat from the body of the insulator which would dip into a cup of oil, the cup being made in a circular form and held in place around the pin by a support on the pin. Insulators with detachable oil cups were supplied for the 10,000-volt transmission at Pomona and San Bernardino, Calif., started in 1892. The oil cups were not used, however, as they were found to be unnecessary.

Insulators without oil cups being equally effective as those with oil cups, a form similar to that shown in Fig. 3, made of either

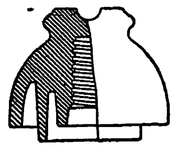


FIG. 3. TRIPLE-PETTICOAT INSULATOR.

glass or porcelain came into use. Here the idea was to impede the leakage of current over the surface by introducing petticoats which gave a very long surface between the conductor and the pin. Some insulators had as many as four or five such petticoats.

No further increase in voltage is noted until 1895, when we find the Hochfelden-Oerlikon transmission in Switzerland at 13,000 volts. In 1897 we had transmissions in the United States at 16,000 volts.

About this time it was found that porcelain insulators which had been formed and pressed in iron moulds had not a sufficiently compact or homogeneous structure and were apt to be punctured in service. A study of the matter showed that really the only effective dielectric insulation of the porcelain was contained in the glaze over the surface of the porcelain. In some cases it was found that the interior body of the porcelain insulator would actually absorb and hold a considerable quantity of water. The manufacture of porcelain was then studied with a view to overcoming these difficulties. The method was resorted to of making the insulator in several thin shells which were glazed separately

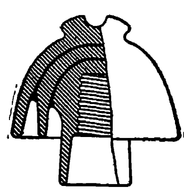


FIG. 4. "GLAZE-FILLED" INSULATOR.

and then glazed and fired together, the potter's wheel being reverted to in order to make the shells of sufficient compactness. This construction is shown in Fig. 4. It will be noted that a petticoat is here extended down for a distance over the pin for the purpose of further insulating from the pin. Attempts had

been made heretofore to extend a petticoat down around the pin, but when the insulator was made in a mould no such long petticoat could be made as was now possible with the insulator made in several parts.

In 1898 we have the first commercial very high voltage plant in operation in the United States, at Provo, Utah. This transmission is at 40,000 volts. The insulator used is of glass, shown

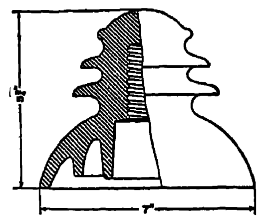


FIG. 5. PROVO INSULATOR.

in Fig. 5. This insulator has outwardly extending petticoats, the purpose of these petticoats being to provide unexposed surfaces near the wire in order to prevent surface leakage.

In 1900 the demands of the Bay Counties and Standard Electric Companies of California, for 60,000 volts, made necessary a very much larger insulator than had ever been made before, shown

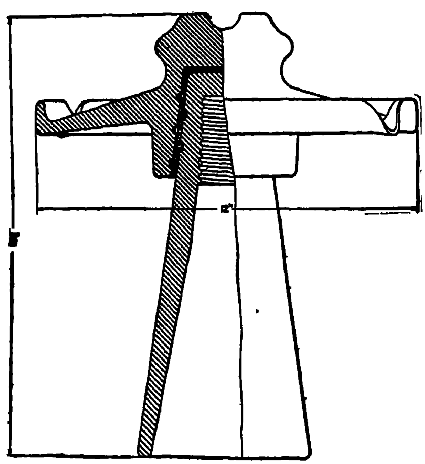


FIG. 6. BAY COUNTIES AND STANDARD ELECTRIC "MUSHROOM" TYPE.

in Fig. 6. In this insulator the outer petticoat is carried out almost horizontally, and a gutter is formed on the top near the edge of the petticoat to conduct water away from the cross-arm.

The top piece of this insulator was originally of porcelain, and the petticoat around the pin, which now amounts to a sleeve extending down the whole length of the pin, was of glass, the glass and porcelain being secured together by sulphur at first and then cement. This type of insulator has been commonly designated the "mushroom" type, from its appearance.

A modification of the outwardly extending petticoat idea is seen in the insulator shown in Fig. 7. This form has had a limited use.

While the insulators enumerated have been referred to in order to show the successive steps in the development of the present highest-tension insulators, it must not be understood that such insulators are not still in use. On the contrary, with the exception of the oil insulator, all of these types and many others possessing the same essential characteristics, are in service, at the various voltages for which they have been found adapted. Even the telegraph insulator shown in Fig. 1 has shown good service in certain localities at voltages as high as 10,000.

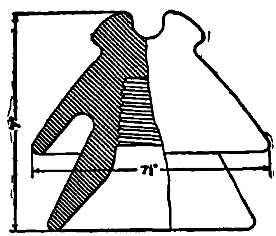


FIG. 7. NIAGARA TYPE INSULATOR.

Insulators of the types shown in Figs. 3, 4, 5 and 6 are in use for voltages as high as 40,000. In various sizes these same insulators are used for all intermediate voltages up to 40,000. Types shown in Figs. 5 and 6 are in use in a few cases at 45,000 volts. Some of these insulators have given good service from the first, while others have failed. It is believed that the failures have been largely due to faulty material. In some cases it has been necessary to replace a whole equipment of insulators because of their faulty construction; in other cases a gradual weeding out has been necessary until the faulty insulators were removed. Occasionally we hear of a plant operating where there has been almost no trouble with insulators, except with such as have been broken by outside interference. In general, it is believed the feeling exists that the line insulator

problem for voltages as high as 40,000 has been satisfactorily solved.

We are now to the point of considering the very highest-voltage insulators—those which are in use for voltages from

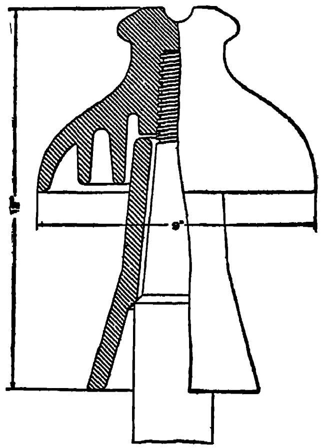


FIG. 8. MISSOURI-RIVER INSULATOR.

50,000 to 60,000. Fig. 8 shows a glass insulator used by the Missouri River Power Company in Montana, for 55,000 volts. This insulator has been in service since 1901. The insu-

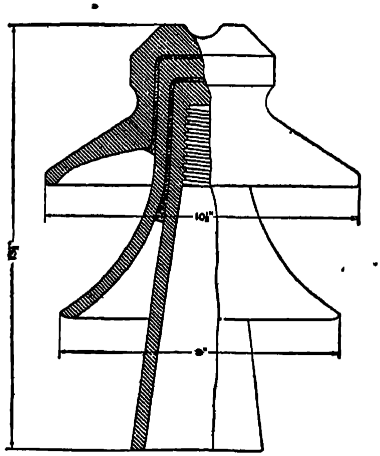


FIG. 9. SHAWINIGAN-FALLS INSULATOR.

lator is in two parts, one a hood 9 in. in diameter, and the other a sleeve set over the pin. The sleeve, which is open at

the top, adds nothing to the dielectric strength of the insulator, its purpose being to protect the wooden pin. Obviously the sleeve would be of little value if a metal pin were used. This type of insulator possesses the advantage of being in two parts which are separable, either of which can be replaced if broken.

The insulator used for the 50,000-volt transmission at Shawinigan Falls, Que., is shown in Fig. 9. This is of porcelain and made in sections. Each section has a closed top and adds to the dielectric strength of the insulator. Two petticoats, one 9 in. and the other 10 in. in diameter, extend outward and give the effect of one insulator over another. One section extends down around the wooden pin and serves to protect the pin. The sections are held together with Portland cement. This insulator

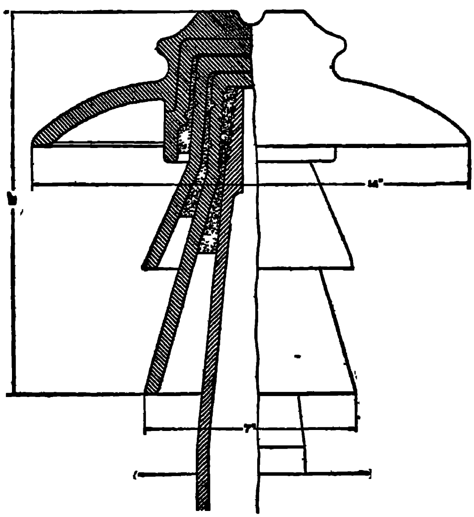


FIG. 10. GUANAJUATO INSULATOR.

shows the combination of the sleeve around the pin, outwardly extending petticoats and of sections, as first indicated in Figs. 4 and 5.

Fig. 10 shows a very large and extended form of the mushroom type, which has recently been put into use on the 60,000-volt transmission at Guanajuato, Mexico. The top section is 14 in. in diameter. The sections are secured together with Portland cement, and the whole is cemented to a hollow metal pin.

For several transmissions under construction for voltages between 50,000 and 60,000, the insulator shown in Fig. 11 has been adopted. Some of these insulators exceed 14 in. in diameter and weigh as much as 25 pounds.

Abroad, insulators are used which are similar to those used in this country. It is probable, however, that they have not been made in such large sizes, also that corresponding sizes are used for lower voltages.

The present highest-voltage insulators, then, of which the writer knows, and which may be considered as representing the most

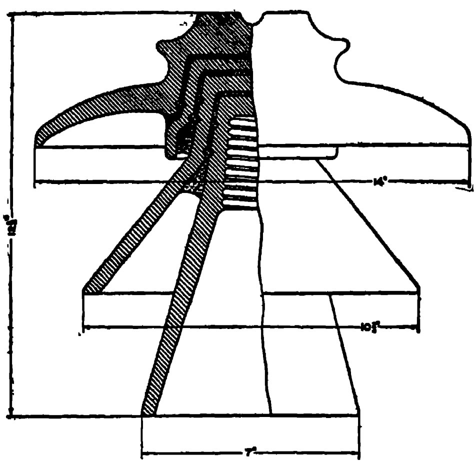


FIG. 11. TYPE ADOPTED FOR SEVERAL TRANSMISSIONS UNDER CONSTRUCTION.

advanced state of the art in insulator design and construction, are represented by Figs. 8, 9, 10 and 11. Whatever advantage one may possess over the others will doubtless be shown in course of time.

Compare now the telegraph insulator, which was used as the first high-tension insulator, with these large ones. Our high-tension insulator has grown with increasing voltages from one weighing a pound or two to one weighing 25 pounds, and from 3 in. to 14 in. in diameter, and in cost from a few cents to several dollars.

We naturally begin to wonder what the future development in insulators will be. Will they continue to increase in size and in weight? If so, we can easily imagine that when an insulator

which is 14 in. in diameter and weighing 25 lbs. is required for 60,000 volts, 80,000 volts might require an insulator 20 in. in diameter and weighing 50 pounds. Further development along this line brings to our imagination insulators which will look not unlike Chinese pagodas and weigh perhaps several hundred pounds, as has been predicted.

This development appears ridiculous when we consider such structures made out of fragile materials like glass or porcelain, yet it is believed that much higher voltages are to be used in the future. Even now we find one company in the United States equipped in every way, except the insulators, to transmit at 80,000 volts. We note also that the largest power development in progress of construction is providing to receive apparatus for 80,000 volts, the amount of power in this case being so large, it has not been considered that it could be always marketed within the range of territory to which it may be economically transmitted at less than 80,000 volts.

Another factor which is tending to make insulators heavier is the steel tower construction for supporting the lines. This construction means longer spans and hence heavier and stronger insulators. Some relief may be given the insulators on these towers by housing them over to protect them from the elements. Some slight advantage may also be gained by securing the wire to the under portion of the insulator, rather than on top of the insulator, as is now done.

It would seem, however, that the trend of development in high-tension tranmission would continue along the lines which have become established. In favor of the further increase in voltage, it must be remembered that there is always the possibility of the discovery of some new insulating material which is superior to glass and porcelain; and even much improvement may be expected in glass and porcelain themselves. While a remarkable improvement has been made in the dielectric strength of porcelain, it is only at the present day that its possibilities are beginning to be realized. Likewise with glass we may expect a complete revolution in the method of manufacture, the art of making glass insulators having been given less thought, and is probably much less advanced than the art of making porcelain insulators.

The requirements for a high-tension insulator may be enumerated as follows:

1). The material must have a high dielectric strength; in other words, it must be strong to resist puncture by the current. In order to fulfill this condition, the material must be continuous, compact and homogeneous, even the most minute crack or fracture being a weakness.

2). There must be sufficient resistance over the surface of the insulator so that there will be no considerable conduction or leakage of current.

3). The distance around the insulator between the wire and the pin or support must be sufficient to prevent the current from arcing.

4). The second and third requirements are dependent upon the shape of the insulator. Its contour must be such that there will be unexposed surfaces which will not get wet or accumulate dirt, salt, etc., as these materials are conducive to leakage and tend to lessen the arcing distance. Evidently the requirements which are dependent upon climatic conditions vary with the locality in which the insulators are to be used. If in a country which is not subjected to heavy rains, sleet or dust storms, the insulator may perhaps be smaller than an insulator required in a locality where the climatic conditions are severe. Usually a larger type of insulator is required for the same voltage in a cold country than in a warmer climate. This may explain why some insulators which have been very satisfactory under a given voltage in one locality have utterly failed when tried at the same voltage in another place. In some localities, particularly on the Pacific coast, the accumulation of salt is so great from the so-called salt fogs that it has been found necessary to have the unexposed surfaces rather shallow and with few petticoats in order that the surfaces be readily accessible for periodical cleaning.

5). The shape and arrangement of the petticoats should be such that the electrostatic capacity of the insulator will be small.

6). The internal heat losses from conduction and hysterisis should not be such as to appreciably heat the insulator.

7). Mechanical requirements, such as strength, mounting, method of fastening the wire, color, etc., are in general, dependent upon the conditions to be met.

It does not seem as if details like gutters, spouts, drip points and the like can be considered of much value. They are features which may look well in theory, but can cut little figure in practice. Certainly the insulation of our high-voltage lines is more

dependent upon a good, strong insulator with liberal margins of safety, than upon such refinements.

The following tests are advised in order to determine whether insulators will meet the requirements:

1). In order to determine dielectric strength, porcelain insulators should be inverted, with their heads dipping into salt water, the solution extending well over the head of the insulator. The hole for the pin should also be filled with salt water. The predetermined voltage for testing may then be applied to the two salt solutions. Usually a voltage test of several minutes is made. The defective insulators will be punctured in this manner. If the porcelain insulators are made in several sections, the purpose of the sections being to obtain greater dielectric strength, then the sections should be tested individually in the same way. When the sections are cemented or assembled to complete the insulator, it is advised to again test, using the same method, in order to be certain that the sections have not been broken. Every porcelain insulator of a lot should be tested in this manner.

If the insulators are of glass it is best to have every insulator tested in the manner described for porcelain insulators, but as the defects in glass are easily visible it may be necessary to test only a few of a lot in order to determine the strength of the glass, the remainder passing the rigid examination of an inspector who will discard such insulators as have cracks, air bubbles, or less than the required thickness.

2). The measurement of leakage over the surface of an insulator is an extremely difficult thing to accomplish, and the refined methods which are required are not applicable to factory tests of a large number of insulators. Any leakage of account will be observed in the test for dielectric strength, either by the visible creepage of the current over the surface, or by the heating of the insulator.

3). A lot of insulators having passed a preliminary inspection, it is necessary to test only a few in order to meet the third requirement. These may be set up as in service and the predetermined voltage applied. It is customary to apply the voltage to the line and pin. It is further advised that a voltage be applied across two insulators mounted in the same way, in order to duplicate as near as possible normal running conditions.

4). In order to test for the effectiveness of the contour of an insulator, it is necessary to imitate as nearly as possible the most

severe climatic conditions under which the insulator is to operate. Tests of this kind have not been extended farther than to obtain the effect of a heavy driving rain. An insulator mounted as for use should have a broken spray of water thrown upon it at an angle but slightly above the horizontal. The results with this combination may then be noted with a predetermined voltage applied between line and pin, or between two insulators similarly treated.

The value of tests should not be overestimated, for it will be recognized, especially as to dielectric resistance, that no laboratory or factory test of the dielectric strength of insulators can approach the time test of insulators in actual service. Consequently it is well to allow a wide margin of safety over the actual requirements. Wide margins of safety in every particular is also good practice in order to compensate for the abnormal voltages which are characteristic of high-tension transmissions. It is questioned whether there is any other element of a high-tension power transmission which operates on such narrow margins as the insulator. Especially is this true in America.

Unfortunately with very high tensions, we are apparently nearing the point where the question is whether there is any margin possible, rather than how much. For a better understanding of the situation, the writer will review the conditions as he has found them.

The electrical requirements of a high-tension insulator are at variance with the requirements for mechanical strength in the following respects:

1). In order to increase the dielectric strength, reduce the capacity and lessen the brush discharges, it is necessary to increase the thickness of the head of the insulator. As the thickness is increased, the pin or support in the insulator is removed farther from the strains of the wire and mechanical stresses are brought upon the insulating material which it is incapable of withstanding. Especially is this true if the wire is tied or supported on the top of the insulator.

2). If the point of support of the wire is lowered to the side of the insulator, it is necessary that the insulator be of large diameter at the point of support in order to have the required dielectric thickness. Also with the wire on the side of the insulator, the surface distance is decreased and the length of the adjacent petticoat must be correspondingly increased.

3). No logical or safe arrangement has ever been proposed

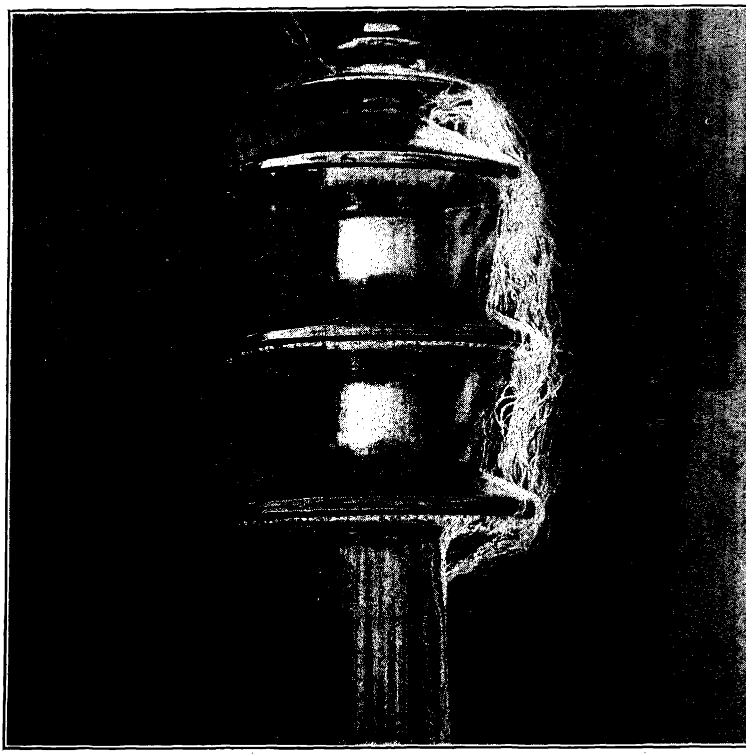


FIG. 13. EXPERIMENTAL INSULATOR UNDER TEST AT 198 KILOVOLTS.

whereby all the lines of a circuit can be supported otherwise than on the tops of the insulators. In this position the surface of the insulator is exposed to the elements, at least as far as the edge of the extending petticoat adjacent to the line, and the effect is to aggravate the cause for leakage for a certain distance, where it must be checked.

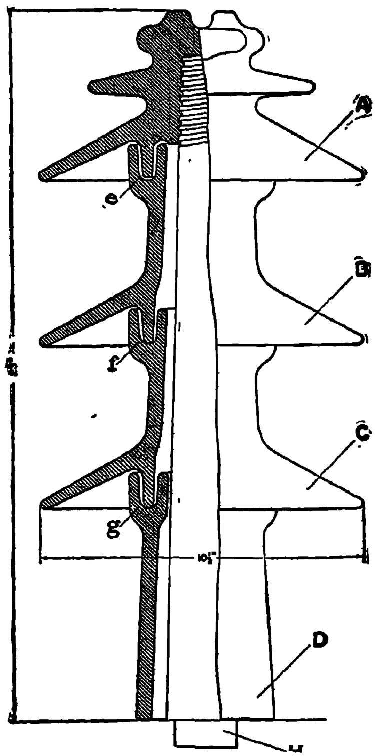


FIG. 12. EXPERIMENTAL HIGH-TENSION INSULATOR.

4). The requirement for a larger insulator means one which is more breakable—if of glass, one apparently beyond the present knowledge of how to mould, or how to anneal.

The electrical requirements are also contradictory in this respect —a larger insulator for increasing the arcing distance adds but little resistance to leakage and probably increases the capacity.

The writer early foresaw the objections to making insulators of constantly increasing diameters for increasing voltages, and proposed the making of insulators in parts and with outwardly extending petticoats. Such construction is shown in Fig. 12. Other

forms of insulators embracing the essential features have been already shown, as in Figs. 9 and 11. The purpose of the construction of the insulator shown in Fig. 12 was to study the effect of the outwardly extending petticoats in resisting arcing of the current between line and pin. The exact details of construction are a top piece, A, screwed onto a wooden pin, H; two like sections, B and C, and a supporting section, D, resting on the cross-arm or support, and holding B and C. D also serves the purpose of protecting the pin. The grooves at e, f and g are for holding an insulating medium, if desirable to insulate between the several parts. These parts being readily separable, it is easy to assemble A and D, or A, D and either B or C. Sections A, B and C are 10½ in. in diameter, and the whole insulator when assembled as shown in Fig. 12 is 23 in. high from the cross-arm. Under test, the terminals of the testing apparatus being connected at the point for the wire and at the cross-arm, the current arced around at the following voltages:

Insulator clean and dry—

A and D,	144	kilovolts.
A, B and D,	186	"
A, B, C and D,	225	"

Under a spray of water at 45 deg., precipitation three-fourths of an inch in five minutes —

A and D,	118	kilovolts.
A, B and D,	157	"
A, B, C and D,	198	"

Fig. 13 shows an insulator under test at 198,000 volts. The spray of water was applied at an angle of 45 deg. with the horizontal, the precipitation being three-quarters of an inch in five minutes. The exposure in photographing was one-half second.

No insulating material was used in the grooves during these tests. There was no tendency for the current to arc between the sections, and there were no serious discharges up the inside of the sections or in the grooves between the sections. This experiment is considered of importance in that the addition of each outwardly extending petticoat section requires a nearly equal additional voltage to produce arcing. The advantage of a properly proportioned insulator with outwardly extending petticoats is, evidently, less diameter for the same resistance to arcing around than an insulator of the mushroom type.

As to the surface conditions on insulators of glass and porcelain;

no differences have been noted in the conduction or leakage of current. With high tensions, such water or moisture as falls on the insulator is quickly dispelled or dried off by the leakage of current, high tensions tending always to keep an insulator dry. In general, losses on high-tension insulators, until a brush appears, are so small that they are negligible. With the brush the losses increase very rapidly with increase in tension.

There remains for the investigator an almost unexplored field for the determination of how the potential may be distributed through an insulator; and not until such knowledge is had may we expect to know the form of the rational design, and learn of the limitations of the high-tension insulator.

Discussion.

Chairman Scott: I am sure we all owe a debt of thanks to Mr. Converse for the very comprehensive and able way in which he has handled this very important subject. The insulator problem is largely a geometric problem, to prevent the surface discharge, and it is a problem of materials to prevent the breaking down of material or the destructive discharge through the material itself. In this problem is involved, in addition to the electrical requirements, the very important one of mechanical strength. It is notable, as Mr. Converse pointed out, that the development of the insulator in use has been limited practically to two materials, glass and porcelain. The introduction, as he suggests, of a new material, a material of good electric properties and good mechanical properties, would probably greatly change the solution of the insulator problem. The insulators which have been presented to us appear rather formidable; they are so much larger than the insulators we had a number of years ago. Each year has seen a larger and more formidable insulator. If we take a comprehensive view of the transmission problem, an expensive insulator is not a vital fault. A transmission plant involves usually large expenditure for hydraulic development, for power house, for machines, for rights-of-way, for poles, for transmission lines, for substations and distributing systems. The insulator, the critical element in the system, is relatively inexpensive. The actual cost of the insulators on one of the important lines in this country, one of the highest voltage lines of a considerable length, amounts to something like 30 or 40 cents a kilowatt, on which the interest charge per year would be one or two cents. That is, the charge per kw-year for insulators on some of the lines which are doing good service, is only a couple of cents. Now, since the total annual cost of delivering a kw-year amounts to many dollars, it is easy to see that we could double, or increase ten-fold, the cost of the insulator, without materially increasing the cost of the whole. There are those here who have had much experience in design and operation of insulators and we hope the discussion will be an interesting one. Mr. Gerry's paper covers somewhat the same grounds as that of Mr. Converse and I have suggested to Mr. Gerry that he present it now and then the whole matter can be discussed.

THE CONSTRUCTION AND INSULATION OF HIGH-TENSION TRANSMISSION LINES.

BY M. H. GERRY, Jr.

There are in America at the present time, about ten systems operating regularly at tensions of not less than 40,000 volts, and transmitting energy from sixty to one hundred and fifty miles. Two of these transmissions employ pressures of between 50,000 and 60,000 volts. The above mentioned systems have all been constructed within the past decade, and while they represent commercial enterprises of considerable magnitude their chief interest lies in the possibilities which they suggest for future developments. The following paper briefly discusses the problems connected with the construction and insulation of transmission lines, without touching upon the generation of the high-tension current, or its manipulation within the generating or receiving stations. The methods of construction and details of design described are drawn entirely from American practice. The term "high tension" where used refers to electrical pressures such as mentioned above.

General Design.

In the construction of high tension transmission lines wooden poles have been used for supporting the conductors almost exclusively, but there is a tendency at the present time to substitute metal, and the more permanent material will doubtless be employed in the future wherever the undertakings are of sufficient magnitude to justify the larger investment. Excellent results have been obtained, however, from the lines now in operation, and the current practice may be followed with a certainty of satisfactory performance and reasonable cost of construction.

Many of the transmission systems are located in a mountainous country difficult of access, and the obstacles overcome have been numerous and varied. Whenever the nature of the service is im-

portant a private right-of-way has usually been secured and two lines of poles erected.

Cedar poles are used in the majority of cases, but redwood, pine and other woods are also employed to some extent. Cedar has an advantage over the other common woods in that it will last longer in moist ground. The pole tops and butts are frequently treated with coal-tar, or some preservative compound, but this practice is not universal. Poles for important transmission lines are usually selected with care, and are heavier and of better timber than those for other classes of service. They are of lengths varying from thirty-five to seventy-five feet, with diameters at the tops of from eight to fourteen inches.

For conductors both copper and aluminum are employed. Copper is used as a solid wire in the smaller sizes, and as a stranded cable when of considerable dimensions. Aluminum is now always employed as a stranded cable. With either metal the flexibility, elasticity and strength are improved when in the form of a cable. Copper may be obtained either soft or hard-drawn. The hard-drawn material has greater tensile strength than the soft or annealed, and for that reason is often preferred. Copper conductors should not, however, be subjected to a greater strain in service than the limit of safety of the soft metal, for the reason that the hard-drawn material may be annealed locally, either during erection while making connections, or while in service by the heating of a joint, or from a short circuit. Aluminum is much the lighter metal for equal conductivity, and this is of some advantage during construction. On account of the greater coefficient of expansion of aluminum, more attention is necessary to temperature conditions at the time of erection, so as to limit the sag and resulting stress developed. Equally good results may be obtained, however, with either metal if properly installed.

The cross-arms in use on most transmission lines are either of fir, or of long-leaf yellow pine. Selected timber is usually employed, and the cross-arms are of special dimensions for this service. In the future structural steel will probably be used to a considerable extent for this purpose.

The pins supporting the insulators are made either of wood or of metal. Of the various kinds of wood, locust, oak and eucalyptus are most in use. Mountain locust from old trees is perhaps the most satisfactory, but is difficult to obtain. Oak if well seasoned

gives good results, and eucalyptus has some excellent qualities. Metal pins are made of steel or cast iron. Steel pins are the more reliable, as they are not subject to flaws, and do not fail from inter-

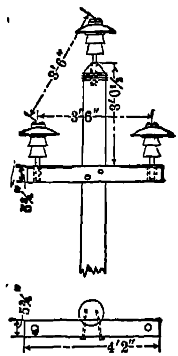


FIG. 1.—POLE TOP FOR HIGH-TENSION TRANSMISSION LINE, WASHINGTON WATER POWER COMPANY.

nal strains. For fastening together the poles, cross-arms, braces and pins, through bolts are now usually employed.

Various details of construction from current practice are shown in the examples to follow.

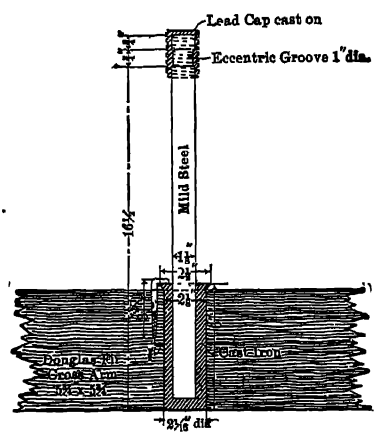


FIG. 2.—STEEL PIN, WASHINGTON WATER POWER COMPANY.

The standard pole construction of the Washington Water Power Company is shown in Fig. 1. This company has recently completed an important transmission, one hundred miles in length, designed

for an ultimate tension of 60,000 volts, although now operating at 40,000 volts. The conductors are of No. 2, B. & S. gauge, medium

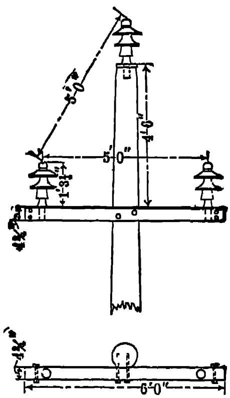


FIG. 3.—POLE TOP FOR HIGH-TENSION TRANSMISSION PLANT, SHAWINIGAN WATER & POWER COMPANY.

hard-drawn, solid copper wire. The insulators are of porcelain and are brown glazed. The distinctive features of this construction are the short distance of forty-two inches between conductors, and

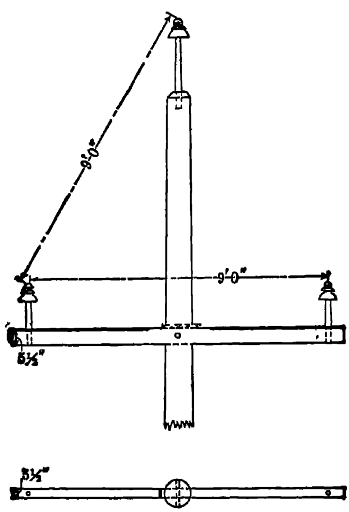
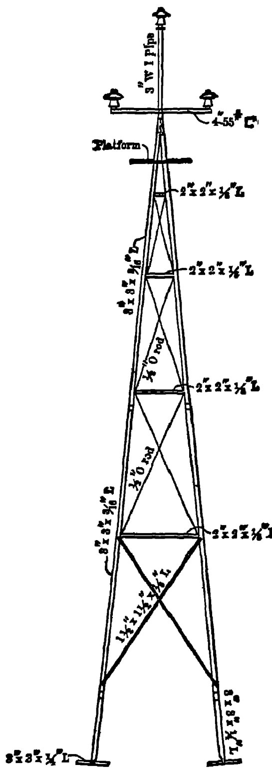


FIG. 4.—POLE TOP FOR TRANSMISSION LINE, MADISON RIVER TRANSMISSION.

the special form of steel pin employed to support the insulators. This pin is illustrated in Fig. 2 and is worthy of notice. It was

designed by Mr. D. L. Huntington, general manager of the company.

Another interesting illustration from current practice is shown in Fig. 3, which is the pole top made use of by the Shawinigan Water and Power Company for their Montreal transmission. The length of this line is about eighty-four miles, and it is now operating at 53,000 volts. The conductors are aluminum cable, each made up of seven strands of No. 7 wire. The insulators are of porcelain, made in three parts, and are supported on wooden pins. They were



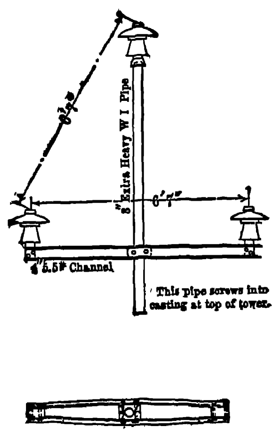
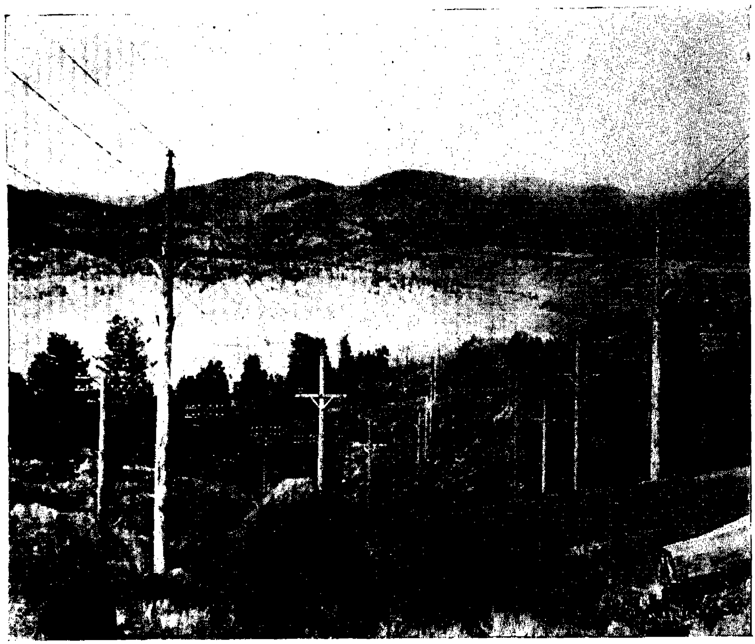


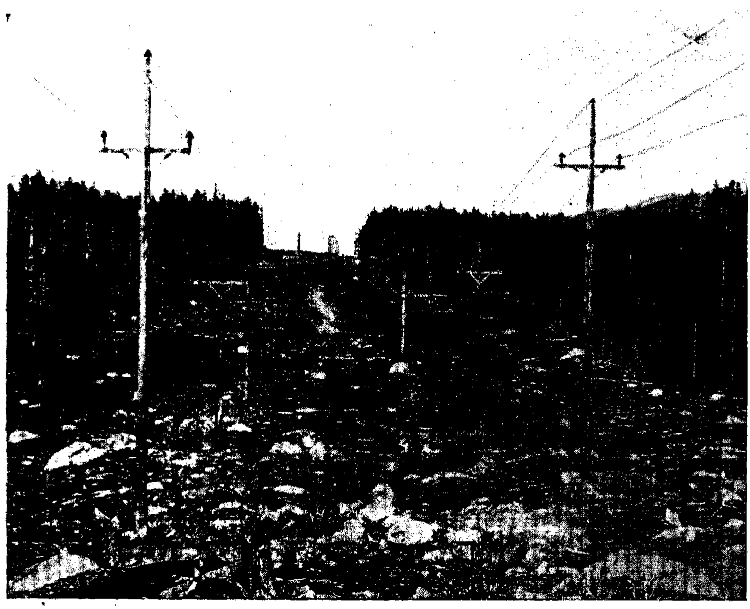
FIG. 5.—SPECIAL FOUR-POST LINE TOWER, GUANAJUATO POWER & ELECTRIC COMPANY.

FIG. 6.—POLE TOP FOR HIGH-TENSION TRANSMISSION LINE, GUANAJUATO POWER & ELECTRIC COMPANY.

especially designed for this installation by Mr. Ralph D. Mershon, the consulting engineer of the company.

A novel construction is shown in Fig. 4. This is the arrangement used by the Madison River Transmission operating into Butte, Mon-





FIGS. 27 AND 28. MISSOURI RIVER POWER COMPANY'S TRANSMISSION LINES.

tana. It is remarkable for the entire absence of metal, with the exception of the conductors. The cross-arm extends through the pole, and is held in place by wooden wedges and a wooden pin. This line is about seventy miles in length and operates at 40,000 volts. It employs glass insulators supported by wooden pins, and the conductors are of aluminum cable. It was built under the direction of Mr. P. N. Nunn.

A transmission which employs steel towers for supporting the conductors, has just been completed in Mexico by the Guanajuato Power and Electric Company. Fig. 5 shows a standard tower, and Fig. 6 the arrangement of cross-arms, pins and insulators. The towers are of a type used for supporting windmills, and are of very light construction, the various parts being fastened together by means of special bolted fittings. All the metal parts are galvanized. The towers are supported by anchors held in place by concrete foundations located at the four corners of the structure. A length of extra heavy 3-inch pipe, supporting the cross-arm and the top pin, extends above the tower. The pins are of cast iron, and the insulators of porcelain. The spans are said to average five hundred feet, while the sag of the conductors is about eighteen feet. The conductors are of hard-drawn copper cable. This transmission is intended ultimately to operate at 60,000 volts.

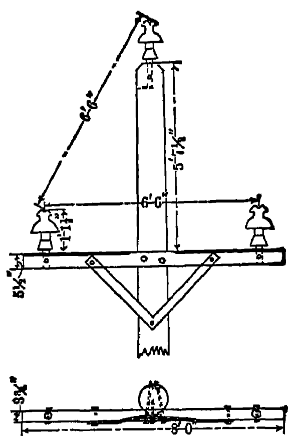
As a further illustration of current practice, the high tension lines of the Missouri River Power Company, built under the direction of the writer, are here briefly described.

This transmission has been in service for over three years, operating at 57,000 volts, delivering power at a distance of over sixty-five miles in a satisfactory manner. The country through which it passes is very rough as shown in Fig. 27.

The lines leave the generating station at an elevation of about 3,700 feet, pass over three distinct summits, including the Continental Divide, at which point they reach an elevation of 7,300 feet above sea level. There are two parallel lines extending from the generating station on the Missouri River to the Butte substation. They are located in the main on a private right of way 200 feet in width, from which all timber was removed. Each of the lines carries three copper cables arranged in a triangular position, seventy-eight inches apart. The cables are composed of seven strands and have an area of 106,000 circular mils. Fig. 7 illustrates the upper part of a standard pole. Fig. 8 is a section of the insulator, sleeve, pin and pole-top.

The poles are of Idaho cedar, the cross-arms of Oregon fir, the braces and pins of white oak, and the insulators and sleeves of glass. The cross-arms, braces and pins are held in place by means of through bolts. The pins in the top of the poles are of larger size and of greater length than those in the cross-arms, to provide for the greater strains there present. The pins were prepared by being first dried and then treated in paraffine, until all moisture was removed, and were then tested to 60,000 volts. The glass sleeves are not fastened to the insulators and merely rest on a shoulder of the pins, as shown in Fig. 8.

The circuits are transposed five times, making two complete turns between the generating station and the substation. The switching arrangements are such that the circuits may be operated



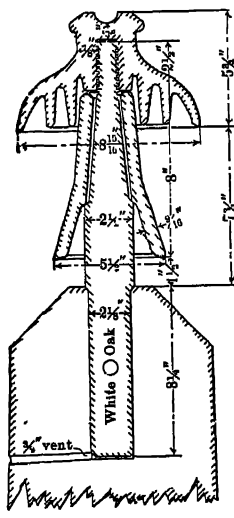


FIG. 7.—POLE TOP, HIGH-TENSION TRANSMISSION LINE, MISSOURI RIVER POWER COMPANY.

FIG. 8.—HIGH-TENSION INSULATOR, SLEEVE, PIN AND POLE TOP, MISSOURI RIVER POWER COMPANY.

either singly or in multiple. A telephone circuit is located on one of the lines and gives good results in service. The poles are from thirty-five to seventy-five feet in length, and the pole-tops are from nine to twelve inches in diameter. The poles are set from six to eight feet in the ground, according to height, and the standard spacing is one hundred and ten feet, with a maximum spacing of one hundred and fifty feet, when required by the nature of the ground. Fig. 28 shows the lines through timbered country.

The constructions just described were selected as typical examples of what has been accomplished in the building of high tension transmissions. Several of the lines mentioned have been in regular operation for periods varying from one to three years, and are in no sense experiments, but rather represent successful commercial undertakings. Other interesting and well-known systems might have been described had the limits of this paper permitted a further expansion of the subject.

Line Insulation.

The design of insulation for high pressure should involve a consideration of all the effects of electrical tension on the dielectric in the vicinity of the conductors. In the case of a line insulator, air is always a dielectric in combination with glass, porcelain, wood or other materials. Wherever there is a difference of electrical potential there exists in the surrounding media a certain state of strain called an electro-static field. This state of strain is the result of electrical stress applied to the insulating material. Dielectrics possess a sort of atomic elasticity, and electrical tensions produce a displacement in the molecular structure which, if carried beyond a certain limit, result in disruptive breakdown of the material. Before a difference of potential can exist current must flow into the dielectric, thus producing a state of strain equal to the electrical stress applied. If the material be not strained beyond its limits of molecular elasticity, current will flow from the material whenever the tension is removed or reduced, and a path provided. All dielectrics possess the quality of receiving strain before rupture, but not to the same degree. Solids and liquids generally possess it in a higher degree than gases. Whenever the limit of strain of a particular material is exceeded it fails structurally, resulting with a solid in a mechanical rupture, and with a gas in a change of molecular state which reduces its electrical resistance and renders it semi-conducting. It frequently happens when several dielectric materials are subjected to the same electro-static field, that one or more of the materials will be strained beyond the limit and will fail, although the others may withstand the electrical tension. Air adjacent to powerful dielectrics frequently fails in this manner, thus giving rise to the common brush discharge.

The structural failure of air, from an engineering standpoint, has been studied by a number of investigators, including Mr. C. P.

Steinmetz and Prof. Harris J. Ryan. It is well known that air at ordinary pressures and temperatures has a much lower dielectric strength than the common solid insulating materials. Air in thin films adjacent to solid bodies has greater strength than in bulk, but is still inferior to such substances as glass, porcelain, mica, treated paper, etc. The dielectric strength of air is affected by its physical condition, and varies directly as the pressure and inversely as the absolute temperature. Under uniform conditions all dielectrics rupture at definite applied tensions. Prof. Ryan has shown that there exists also for each dielectric material a certain strength of electro-static field which will cause rupture. When several materials in series form the dielectric, the one rupturing at the lowest value of electro-static field will fail first although individually it may possess superior qualities.

Line insulators are usually made of glass or porcelain, fashioned into a variety of shapes, all approximating certain elementary forms. Consider that alternating electrical tension be applied to a solid

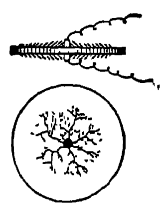


FIG. 9.—TENSION APPLIED TO DISC.

insulating disc, as shown in Fig. 9. If the pressure be low, only charging current will flow, but if the tension be increased sufficiently the air under and about the electrodes will be ruptured, producing brush discharge. This results in the formation around the electrodes of a zone of ionized air, of comparatively low resistance. This enveloping zone of conducting air has the effect of increasing the size of the electrodes, and thus the area to which the full tension is applied. If the tension be further increased, the zone of ionized air continues to spread over the surface of the disc, thereby increasing its capacity and the resulting charging current. Streamers will now form on the surface of the plate, and thus afford a path of still lower resistance whereby the current for charging the dielectric and ionizing the air is conducted to the outer portions of the ruptured zone. When the surfaces of the solid dielectric are parallel, as in this case, the streamers and ruptured air zone when once

started, would apparently continue to spread indefinitely, were it not for the cooling effect of the adjacent material, the appreciable resistance of the path through the ionized air, and the time element introduced by the alternating pressure.

Under the conditions as shown in Fig. 9, the streamers may unite over the edge of the plate, thus forming a short circuit, the distance travelled being several times as great as the breakdown distance through air for the same pressure. This result is not due to surface leakage, as frequently assumed, but is a phenomena of electrostatic capacity and local structural failure of the air as a dielectric. If instead of the pressure being applied to a small area, as

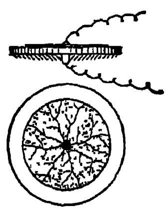


FIG. 10.—TENSION APPLIED TO DISC BY MEANS OF ENLARGED ELECTRODE.

in Fig. 9, the electrode be enlarged to a plate, as shown in Fig. 10, the same results will follow, but the spreading out of the ruptured air zone will take place on one side only and at a considerably lower tension. If pressure be applied to an insulating tube, by means of

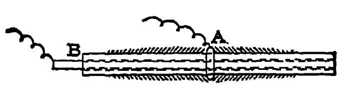


FIG. 11.—TENSION APPLIED TO INSULATING TUBE.

a conductor inside and outside, as shown in Fig. 11, the air will fail at a certain tension, and the results will be similar to those obtained with the plate, in Fig. 10. The streamers will start from the conductor on the outside at *A*, and will run along the tube from the center toward the ends, the tendency being to cover the outer surface with an enveloping coating of ruptured air.

In this, as in all other cases, the streamers are drawn out in such a direction as to increase the electro-static capacity. If a still greater tension be applied, the streamers from *A* will finally draw sufficiently near to *B* to cause rupture of the air in bulk between *B*

and the ends of the streamers extending from A. If, under these conditions, the internal conductor be now removed from the tube, as shown in Fig. 12, the air about the point A will no longer be ruptured, and the streamers will cease, although the distance between A and B, and also the conditions for surface leakage remain as in Fig. 11. It will now require a material increase of tension

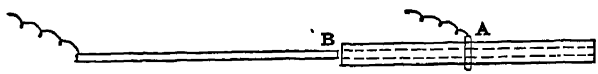


FIG. 12.—TENSION APPLIED TO INSULATING TUBE, INTERNAL CONDUCTOR WITHDRAWN.

to cause a breakdown between the electrodes, and this will occur essentially as if the tube were not present.

After initial rupture of the air, the spreading of the streamers

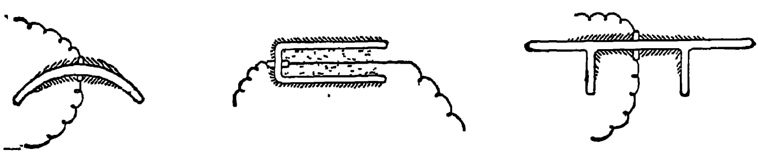


FIG. 13.—TENSION APPLIED TO INSULATING DISH.
FIG. 14.—TENSION APPLIED TO INSULATING RECEPTACLE.
FIG. 15.—TENSION APPLIED TO SPECIAL FORM OF INSULATOR.

is affected to a degree, by the form of the solid dielectric. Fig. 13 indicates tension as applied to a dish of uniform thickness, Fig. 14 to a deep receptacle, and Fig. 15 to a special form. The results obtained from the arrangement shown in Fig. 13 will not differ materially from those obtained from the arrangement shown in Fig. 9, or if one surface be made conducting, from those obtained from Fig. 10. In the case of Fig. 14, however, the air in the interior of the receptacle about the entering conductor becomes ionized at sufficient tension, and the conditions then existing are the same as if the receptacle were filled with a conducting substance. With the arrangement in Fig. 15 the streamers start as in Fig. 9, but upon reaching the downward projection they are forced along its surface and away from the streamers on the upper face of the plate, until a point is reached where the electro-static field is no longer sufficient to rupture the air, when the streamers die out and further spreading of the ruptured air zone ceases.

All line insulators are made from variations of the forms just

discussed. Surface insulation has little to do with their performance, and excepting the faces be made conducting by a coating of water or other foreign material, the surface leakage may be neglected altogether from an engineering standpoint. A wet surface, however, is practically equivalent to the metallic coating illustrated in Fig. 10. For high tensions wet surfaces should be considered as conductors, but dry surfaces need be treated only in relation to the electro-static phenomena already described.

A first consideration in connection with the design of a line insulator is its ability to maintain dry surfaces under all weather conditions. It has been frequently assumed that rain descends at an angle not exceeding 45° from the vertical, but this is not a safe basis for design. When rain is accompanied by wind at high velocity, and especially if the air currents be unsteady and in "gusts", and subject to deflection on account of the irregular contour of the country, it will then be found that at times the rain travels practically in a horizontal plane. As the rain-drops are often moving at high velocity, there will be also considerable splashing of the water where it meets obstructions, and this must be considered in predetermining the dry surfaces. With insulators of the "umbrella" type, there frequently results a wetting of a portion of the under side of the main petticoat, from water splashed from other parts. The shape of the insulator may also result in deflecting the air currents, thus carrying the rain to surfaces that otherwise would remain dry. Insulators of the "Italian" and "Double-Story" types are frequently affected in this way. Those of the vertical petticoat type are especially free from this defect, as the spaces between the petticoats are efficient in preventing eddying air currents from carrying moisture to the under side of the insulators.

After determining the extent of the possible wet surfaces, consideration should be given to the distribution of potential on the various parts of the insulator. The tension is applied between the point where the conductor is attached and some other point, depending upon the construction employed. During rains the entire upper surface of the insulator is at the potential of the conductor, and the ground potential is at the least directly under the insulator at the cross-arm. This condition holds with wooden construction as well as with metal. If a conducting pin be employed, the ground pressure will be carried still higher, and the tension will be applied across the comparatively thin material of the upper part of the insulator. The dielectric will then consist of the porcelain or

glass at this point, and the air adjacent to the conductor and pin. The tension will be that to ground, and for a three-phase circuit under normal conditions, will be less than the pressure between conductors, but as there are many operating conditions where full tension may be applied to the insulators, it is better practice, for the purpose of design, to assume that this is the case at all times. The form of the pressure curve also has an effect, as it is the maximum tension at the peak of the curve that causes initial failure of the dielectric.

If the tension as applied sets up through the material an electrostatic field sufficiently powerful, the air in series with the solid insulating material will be ruptured, and brush discharge and streamers will form, which unless checked, may extend over the entire insulating surface, causing short circuit. The spreading of the conducting zone of air may be prevented as previously explained, by the use of very large surfaces, or by employing deflecting projections, or petticoats, so arranged as to reduce locally the strength of the electro-static field to a point at which the air will not be ionized. These methods, however, serve only to stop the spreading of the ruptured air zone, and require considerable dimensions for even low factors of safety. All brush discharges are wasteful of energy, and are destructive of organic materials. It is brush discharge combined with capacity charging current that has caused the burning of pins on high tension lines. Common wooden pins are practically conductors for high tensions, and the ground pressure is carried up within the insulator. When the pins possess dielectric qualities comparable with the material of the insulators, the tension may be said to be applied between the top and base of the insulator, resulting in a greatly increased thickness of the dielectric material. This usually overcomes brush discharge and materially increases the reliability of the insulator. For the best results insulators for high tensions should be so designed that under no operating conditions would the electro-static field of force ever be sufficient to rupture the air adjacent to the insulating surfaces. This can be accomplished by properly proportioning the thickness of the material exposed to the electric stress.

The general dimensions of the insulator should, of course, be such that the direct air path from the conductor to the cross-arm will be sufficient to avoid failure through the rupture of the air in bulk. This is a matter of simple determination, involving only the length of the air path and the dielectric strength of the air in bulk at the

extremes of pressure and temperature, as found in service. When insulators are made of several parts cemented together, the dielectric material is no longer homogeneous, and the distribution of the electro-static strain may be materially altered. The cements commonly used, such as sulphur, litharge and glycerine, Portland cement, etc., possess entirely different and inferior electro-static qualities to the glass or porcelain of which the insulators are made. The cement between the sections is in series with the dielectric material of the insulator, and is exposed to the same electro-static field of force. The strata of cement in some cases redistributes the electro-static charge. Under other conditions, the pressure is conducted directly to the cement through the ruptured air. In this case the semi-conducting cement becomes charged with practically the full terminal pressure, and excessive tension may thus be applied to a section of the insulator not designed to withstand it. This frequently results in sectional breakdowns, and the insulator fails in detail. The irregular distribution of surface potential also affects the outside air path, and in some types of insulators reduces the tension required to rupture the air between the points of applied tension. When insulators are made up of several parts, the cement employed should possess dielectric qualities comparable with that of the component parts, and every effort should be made to render the dielectric material homogeneous so that there may be a uniform fall of potential between the points at which the tension is applied.

The resistance to disruptive breakdown or puncture of the solid dielectric is also of importance. Good porcelain or glass has, however, such great strength in resisting puncture that if the insulator be designed so as to entirely avoid rupture of the air near the points of applied tension, it will be impossible to puncture the insulator under operating conditions. One-piece insulators of glass or porcelain seldom fail from puncture, even if thin at the top, but two or three-part insulators sometimes fail by puncturing one or more of the sections, probably due to unequal distribution of potential, as previously discussed.

Of the various substances available, glass and porcelain have been used almost exclusively for high-tension insulators. Glass has excellent dielectric qualities, and can readily be obtained in desirable shapes, at reasonable cost. Its greatest defect is its mechanical weakness, which is due almost entirely to internal strains developed during manufacture. Consistent design of the surfaces so as to obviate as far as possible shrinkage strains, and careful annealing

have improved the conditions of many glass insulators so as to render them reliable for service, but they still do not possess the mechanical strength of the best porcelain. Glass, however, is a more reliable dielectric material, and from an electrical standpoint gives better and more uniform results. The best porcelain has great mechanical strength and good dielectric qualities. It is, however, difficult of manufacture in considerable thickness, and is very apt to develop flaws and surface cracks. Common grades of porcelain are unreliable and should not be used for high tension work.

While the insulator has been considered chiefly as an electrical device, it is still essential that it be treated as a mechanical support for the conductors, which function it chiefly serves. Practically all the mechanical strains on the insulators and pins are transmitted from the conductor. When the line is level and without angles, and when the spans are equal, the strains are due only to the wind and weight of the conductor. When angles in the line occur, a transverse strain is developed. If the line be not level or the spans not equal, strains having vertical and horizontal components are produced. All the necessary calculations for the forces acting and the resulting strains can be readily made by the ordinary rules of mechanics, and do not here require consideration.

The following described high-tension insulators were selected as representing American practice:

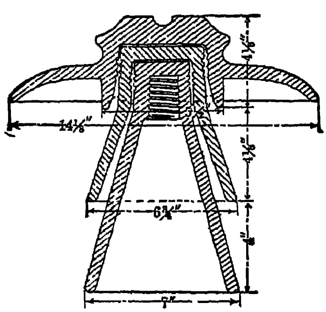


FIG. 16.—SECTION OF HIGH-TENSION INSULATOR.

Fig. 16 shows a brown glazed porcelain insulator, of the "umbrella" type. It is made in three parts cemented together, and weighs about 20 lbs. This insulator is in use by the Washington Water Power Company already referred to in this paper.

FIG. 21.

FIG. 22.

FIG. 24.

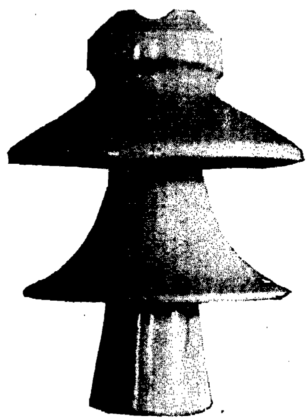


FIG 23.

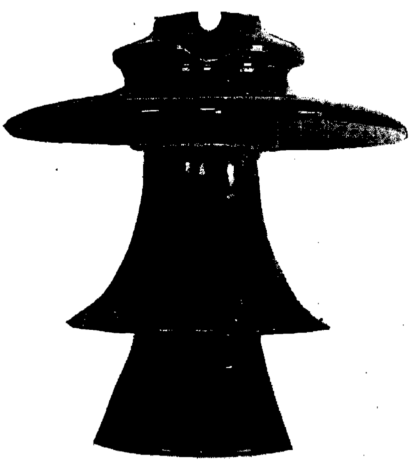


FIG. 25.

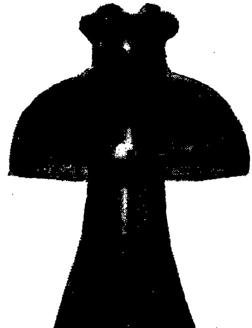


FIG. 26.

FIGS. 21 TO 26.—HIGH TENSION INSULATORS.

Fig. 17 is a section of a glass insulator also of the "umbrella" type. It is made of two parts cemented together, and weighs 13 lbs.

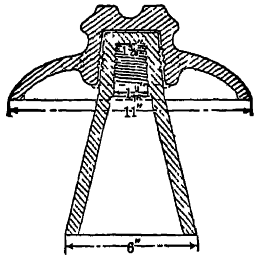


FIG. 17.—SECTION OF HIGH-TENSION INSULATOR.

Fig. 18 shows the insulator in use by the Shawinigan Water and Power Company, now operating at 53,000 volts. It is of white

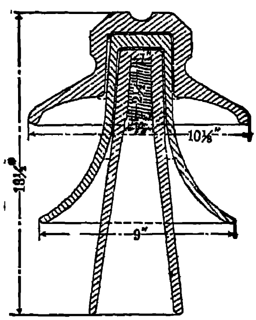


FIG. 18.—SECTION OF HIGH-TENSION INSULATOR.

glazed porcelain, in three parts. Its dimensions are given in the section. This insulator also weighs 13 lbs.

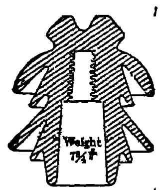


FIG. 19.—SECTION OF HIGH-TENSION INSULATOR.

Fig. 19 is a single-piece insulator of the "Italian" type. It is made of fine porcelain, brown glazed, and weighs 7¾ lbs.

Fig. 20 shows a porcelain insulator of late design. It is brown glazed and made in three parts. Its weight is 26 lbs.

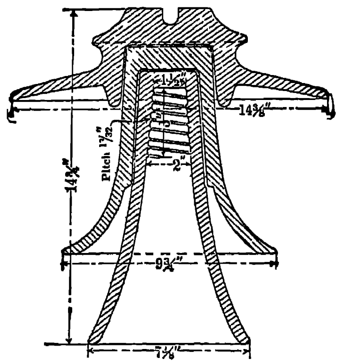


FIG. 20.— SECTION OF HIGH-TENSION INSULATOR.

The insulator shown in section in Fig. 8 is the standard insulator of the Missouri River Power Company and is in regular service at 57,000 volts. It is of glass made in two parts, and its weight is $12\frac{1}{2}$ lbs.

Figs. 21 to 26 inclusive are reproductions from photographs of the insulators shown by the section drawings above referred to.

The developments in the construction and insulation of high tension lines have now reached a point where no doubt exists regarding the practicability of transmitting energy at tensions approximating 60,000 volts. From this time on it will be rather a question of expediency and engineering detail to determine the best methods of obtaining the desired commercial results. For pressures above 60,000 volts the field as yet is unexplored, but those who have followed this subject carefully agree that much higher tensions will ultimately be employed. The practices discussed in this paper, both for the general construction and for the insulation of high tensions, cover what has already been accomplished, but seem also to point the direction of future development in this branch of engineering.

DISCUSSION.

MR. GERRY: In opening the discussion on Mr. Converse's paper, I wish to call attention to one or two points in connection with insulator design which I believe have been overlooked. This has resulted, among other things, in the discussion of the relative merits of iron and wooden pins. There is little ground for discussion on this point; both iron and wooden

pins have their respective values in particular cases. When properly applied, either will answer the purpose. Furthermore, because of these certain points having been overlooked, the great differences have arisen in high-tension insulator designs. I have recently examined an insulator weighing 50 pounds, having petticoats 36 inches in diameter, but it did not possess proportionate strength for withstanding the ordinary conditions of line operation. Mr. Converse has stated that surface leakage has an important bearing on insulator design. My experience has been that leakage, as it is ordinarily understood, plays little or no part from an engineering standpoint. Unless the surfaces be covered with water, salt, or some conductive powder, there is no appreciable leakage of current. However, a somewhat similar effect on the surfaces may be produced by a film of ruptured or semi-conducting air, resulting from the application of too great electro-static strain. The electrical tension is applied to the opposite sides of the solid dielectric, but in an insulator the dielectric includes, in addition to the glass or porcelain, the air immediately surrounding the electrodes. Under these conditions, when pressure up to a certain point is applied, very little current flows into the dielectric — only the small amount required to charge the material immediately adjacent to the conductors. If the tension be now increased, a point is finally reached at which the air near the electrodes is ruptured. This results in what is commonly known as brush discharge. The air becomes semi-conductive, and the electrode in effect expands, causing the charging current also to increase. This seeming expansion of the electrode, when once started, would go on indefinitely were it not for certain conditions tending slightly to retard it; such as the cooling effect, shape, and nature of the surface of the solid dielectric, and the time limit introduced by the current wave.

What actually happens, after the air is ruptured, is that the brush discharge finally extends over a certain limited area on both sides of the insulator. A comparatively slight increase in the potential applied will now greatly increase this area. In nearly all insulators recently designed, the solid dielectric is thin at the top where the tension is ordinarily applied. It follows that the air at this point is easily ruptured, and the brush discharge spreads from the electrodes over the surface of the insulator. Once started, it requires only a moderate increase in the tension to cause this brush discharge and its accompanying zone of ruptured air, to extend such a distance that an arc starts and a breakdown of the insulator results. Metal pins or wires inside the insulator, cause the tension to be applied directly across the thinnest part of the insulator, while insulating pins if of proper quality, form a part of the main dielectric, resulting in the tension being applied at more widely separated points. With most insulators in common use, conducting or semi-conducting pins have been employed, and this accounts for the very narrow margin of safety mentioned by Mr. Converse in his paper. This factor of safety may be increased, however, by consistent designing of the insulator, or by the use of an insulating pin. It is thus possible to increase many times the thickness of the solid dielectric to which tension is applied,

thereby enormously increasing the factor of safety under given conditions. If an insulator such as shown by Mr. Converse in Fig. 8 be supported on an insulating pin, it will be impossible to break it down, except through the main air path, and brush discharge will not start until the air in bulk is about to fail between the points at which the tension is applied — the tie wire and the cross-arm. This result is due to the fact that the solid dielectric is then of sufficient thickness to prevent the formation of a sufficiently strong electrostatic field to rupture the air prior to the point of rupture being reached through the direct air path. This is one of the points to which I wish to call attention, and it is of the greatest importance in connection with insulator design. If high potentials are to be applied to very strong and comparatively thin dielectrics, the air is bound to rupture, and it will be necessary to resort to extreme sizes of petticoats to prevent the spreading of the brush discharge thus formed. If, on the other hand, a more logical design be followed, and the insulator so proportioned, that brush discharge will not result, then the insulator may be strained practically to the point of failure of the air between the points where the tension is applied.

Chairman SCOTT. If we consider both high-tension commercial service and time, I believe we must accord to Mr. Gerry the honor of having operated at the highest voltage over the longest time. He has been operating nominally at 50,000 volts but actually at 55,000 volts, in continuous commercial service for two years and a half. His line is about sixty-five miles from the power house of the Missouri Power Company, near Helena, to Butte, Montana. Other plants have operated at a little higher voltage, others have operated at longer distances, but taking all together — high voltage, length of time, continuity of service, amount of power — his plant may be taken as one of the foremost if not the foremost example of high-tension transmission at this time. I believe he told me that he had not lost an insulator through break-down on the line due to electrical causes.

Mr. CONVERSE: Mr. Gerry prefaced his remarks by the statement that his ideas of the essential features in the design of an insulator were somewhat at variance with those expressed in my paper. On the contrary, I think we closely agree as to one of the most serious defects in the design of high-tension insulators, which is the lack of a sufficient thickness of material around the head. Mr. Gerry mentions the brush discharges which occur around an insulator, and I believe made certain experiments with dielectrics of different shapes in order to show the character of the brush discharges. He then applies the experiments in the design of an insulator and, I infer, finds the proportions of the insulator. Mr. Gerry's analysis discloses nothing new, and its results are rather doubtful. It would seem to be desirable to devise some way of measuring the potential differences between the various parts, in order to determine the rational design. I am inclined to agree with Mr. Gerry that wooden pins have been burned by the brush discharges and not by surface leakage of current. As to whether an iron pin will become a detriment in a very high-voltage insulator, I am in doubt; but incline

to the belief that it may be found to be the means of securing the proper distribution of potential.

Dr. F. A. C. Perrine: In these two papers, two essential elements in insulator design are stated, namely, that the potential gradient from wire to ground, whether the ground be pin or whatever it be, shall be as gradual as possible, and that all surfaces exposed shall allow as complete a distribution of potential as is possible. These two principles, I think, are the absolutely essential elements of insulator design, and it is fortunate that in the midst of a lot of floundering, the men who have been actually building high-potential insulators have at last arrived at a correct scientific theory of the design of an insulator. Mr. Gerry has, fortunately for me, expressed very clearly the first principle. If we have two surfaces charged, then the tendency to break down the air is proportioned to what we may call the potential gradient from one surface to the other. As we narrow their distance, the potential gradient becomes steeper and there is more tendency to discharge around their edges. The other point is simply the question of discharge between surfaces. We all know that if we have two points presented to each other, there is a greater tendency to discharge than if we have two planes. We have at the petticoat edge of every insulator what is essentially a line of discharge. Now, to reduce the tendency to discharge from a line to any surface, we have to present to that line a semi-cylindrical surface. If we have in equivalent position a plane surface, there is more tendency to discharge to the nearest line in the plane than if an equipotential semi-cylindrical surface was presented at a distance equal to the minimum distance of the plane. In consequence, in all insulator designs, we will have the least tendency to discharge from the circular line formed by the bottom of a petticoat which is a conducting line, as Mr. Gerry has explained, in every rain storm, if the next surface to which it can discharge is an equipotential surface. That insulator is the best which has the lowest gradient of potential from the wire to ground and which has from its conducting points relatively dry surfaces in the next step to earth, which are described as circles around those conducting points. It is very nice to say that this is all theory which we have known for years. That may be true. At the same time we have not been applying it for years, and we have not understood its application to insulator design, and it is only through the work of such men as Mr. Gerry and Mr. Converse that we have been brought back to what Maxwell actually taught us about insulators. The most successful insulator design that I know has been carried out on these lines, and that insulator is one which has obtained a higher value of its breaking-down strength than any other that I have known tested, for its weight and inches. This insulator, which I think weighs about twenty pounds and is fourteen inches in diameter at the top, has its end of petticoats curved on the radius drawn from the line of discharge, the beginning of the circle being the horizontal distance where we may be sure that it is dry. This form of insulator is perfectly quiet in operation at 120,000 volts, in ordinary weather. In a severe shower from a hose it discharges over at about 107,000 volts. This particular insulator (referring to another design in Mr. Converse's paper) is an insulator which weighs over forty pounds, has

three inner petticoats, and discharges over at about 2000 volts less than the insulator (last described), although there is less than half the material in the latter. The arcing distance of any insulator can generally be calculated correctly by the nearest distance between these points which are wet and the next neighboring petticoat; simply add those distances together and look at your table of sparking distances, and you will generally find very closely the potentials at which the insulator would discharge under severe water conditions.

Dr. LOUIS BELL: One thing which should be brought vigorously to attention in these questions of insulator design is the possibility of getting practicable porcelain or glass for the work. By some strange fatuousness in the last few years each insulator designer has striven to outdo the others in size. Now, where you are attempting to stop leakage, it does not seem to be very advantageous to increase largely the surface over which leakage is possible. One would say that the less area and the greater linear distance along the line of potential gradient that can be obtained, the better off you would be. The consequence is we have had insulators rising from five, six, seven, ten inches in diameter up to that bath-tub of which Mr. Gerry spoke, which could be guaranteed off-hand to fail simply on account of the impossibility of getting porcelain of that size that is worth the power to blow it up. You cannot take a mass of cheap porcelain that you are trying to produce at the minimum figure, and get any valuable insulating qualities. By correct design not only is it possible to get longer distances so far as the striking is concerned, but it is possible to reduce the size and weight of the whole thing so that at least there is a possible chance of getting good porcelain. That, I think, is the line along which future design has to advance — to design scientifically, get all out of your material you can in the way of distances. The dielectric strength will generally take care of itself. I have seen so many bad porcelains turned out for these insulators, procelains that you really wouldn't want in a baking dish, the cheapest kind of porcelain, shabby, with holes in the glaze and with the biscuit of the porcelain porous enough to take up water like a sponge. Those bad porcelains come with an attempt to make these enormous structures which really have not as great efficiency as the smaller structures. And as regards the question of wooden and iron pins, as Dr. Perrine has stated, it comes right down to a question of potential gradient. If you think the insulator will sustain the potential gradient, very well. Design your insulator so that it will sustain it and you will have no trouble with iron pins. I think there is no question in the mind of anybody who considers an insulator from the standpoint of potential gradient, that if you had a porcelain pole you need not worry about your insulators very much. Well, wood is a great deal worse than the porcelain, but at the same time a well treated pin, such as Mr. Gerry has referred to, is a great deal better as an insulator than soft steel. And if you are on the ragged edge of practicability with your insulator, you want all the insulating strength near it that you can possibly get. The question between wood and steel seems to be the question of fact as to whether we can get, under practical conditions, an insulator that will give

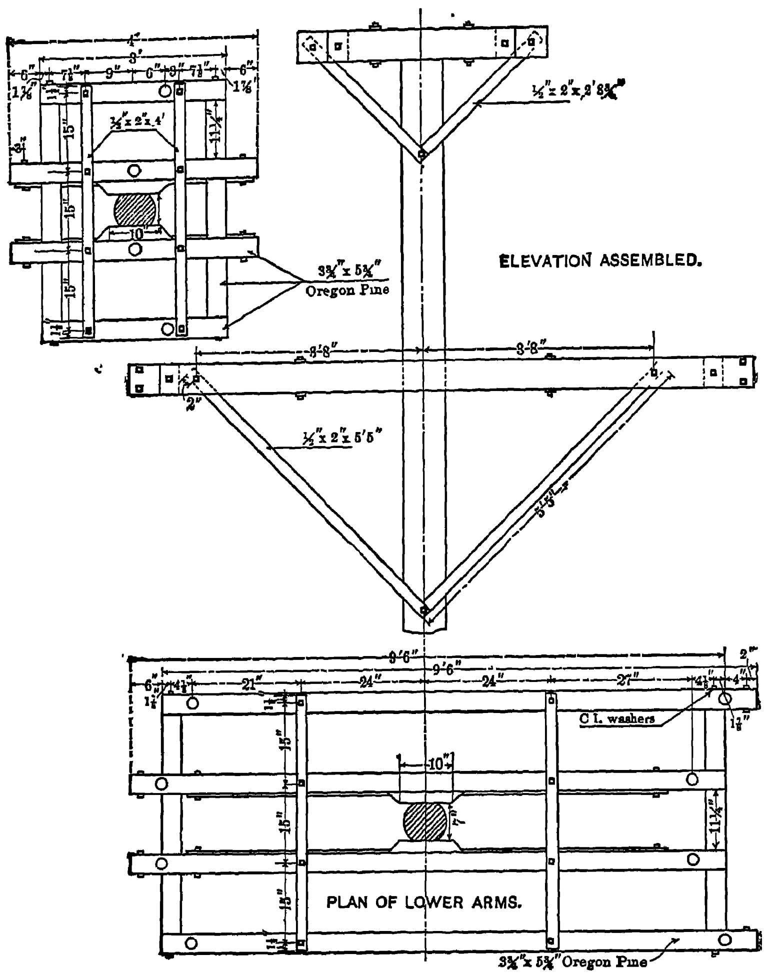
an adequate factor of safety while still carrying the earth's potential right up into its interior. It is not a question of theory at all; it is simply a question of fact. If you can get an adequate factor of safety in that way, all very well.

Mr. E. KILBURN SCOTT: I would like to ask the author whether he has any experience as between the relative values of brown and white procelain? We find in England that the brown is not such an attractive mark for the small boys' catapult; but there is a feeling that the brown is not so good an insulator. Of course, the main thing in high-tension insulators is to get a vitrified material, which, when it is broken, shows a bright surface right through and which is not spongey or absorbent. What method is adopted for fastening or cementing the iron pins to the porcelain? If the iron is simply screwed into a thread, the porcelain is liable to crack off. I believe it has been suggested that a worm of lead should be placed between the threads of the iron and the porcelain. If such has been tried, I would like to know whether it has been successful. If I might criticise the author's design of a composite insulator, I think that a side-stress would cause the edge of the porcelain to chip badly where they come together. At the same time I consider it is a good thing to cover up the pin with porcelain. This was done with the Ganz insulators on the Valtellina Railway; but the pins in this case were of iron. With wooden pins, it might prevent sparking to the wood. I understand that these sparks gradually make tiny pin-holes, and it is only a question of time when sufficient pin-holes will cause the pin to collapse.

Mr. CONVERSE: The last speaker evidently has not understood that the purpose of the insulator shown in Fig. 12 was for an experiment, and not introduced as a commercial type. The results with the insulator, however, are along the same lines as Dr. Perrine has shown, except that I think Dr. Perrine furnishes a possible improvement in the shape of the outwardly extending petticoats.

Mr. R. S. HUTTON: Fig. 11 is about the form of insulator that we are using on the coast. The paper shows one that has a little trough around the edge with a drip-point on it. Those are the ones we formerly used, and what we call the eleven-inch insulator. Some of the types shown have given us trouble down near the ocean in the salt-air district, as we call it. Those insulators have all been tested on the rack and stand the test; but after they are put on the line, we find that after a time the wooden pins burn off. After taking one of these apparently defective insulators from the line, thoroughly cleaning it off, and putting it back on the test rack, it stands the test of 120,000 volts perfectly. The separate parts of the first ones used, were put together with sulphur, and we had some field fires that we were not able to account for. We afterwards found out that it was due to the fact that the leakage heated the insulator to such an extent that the sulphur was set on fire, and as it dropped down, set the grass on fire around the poles. We have now adopted a metal pin, made of the ordinary gas pipe; we are using 1¼-inch pipe, which is drawn down at one end and slightly roughened, so that a lead sleeve with threads can be cast on. These we find have given very satisfactory results. We find this particularly true for the reason that

having such a tall insulator, when we used wooden pins, they did not have sufficient strength, particularly for corner work. The iron pins stand up perfectly straight, keep their position, providing the balance of pole-top is properly constructed. We have recently adopted a new corner



pole-top. (See accompanying illustration.) This is a form we use where we have a heavy angle, even as high as a 90-degree angle in a line. Instead of setting two poles for a corner, we now use but one, for we very often find, particularly in running through a city, that it makes the construction look rather unsightly, to put two poles on a corner; and in giving the proper distances, between the poles, it brings one of them around on the street directly in front, in such a way that it interferes with people's

property. We find that if we put one pole on a corner we can get along much more agreeably. It will be noticed by examining the illustration that these pin-holes are spaced in such a way that on a 90-degree angle there are 22½ degrees deflection on each insulator. With this arrangement, the corners stand up very prettily. The insulators have no tip to them at all. The cross-arms are made long enough in these cases so that the spread of the wires is exactly the same as it is in other parts of the line. I would like to ask Mr. Gerry if this type of insulator has even been tested with a metal pin or with a metallic sheeting around it, with metal in the top, or metal pin?

MR. GERRY: It was tested until the potential went clear around. When the potential was applied below it did not break through. This applies to an insulating pin, the dielectric qualities of which compare favorably with those of the glass. Such a pin may be of wood. Of course, wood is not an ideal material for an insulator because it is unreliable in some respects, but by proper treatment, especially with the vacuum process, it becomes an excellent dielectric. With such a pin supporting the insulator the results will be as I have stated.

MR. HUTTON: That is on the assumption this pin is absolutely dry. It seems to me that where we have trouble with the fog, the under part of the insulator gets just as wet as any other part. Sometimes we have the land fogs without any wind whatever. This is due to the steaming of the land, from the fact we have the under-flowing water in the gravel beds and the coldness of the atmosphere above makes the ground steam and the fog simply rises and practically steams the insulators. The reason I asked Mr. Gerry about that particular test is because on this other insulator we usually test by raising the potential until the arc goes clear around the insulator, and if there be any weak points we find that the spark strikes at some point to shorten the distance, and I was wondering how that air gap would stand if you used a metal pin. What I want to get at is whether that particular form would be of any use with a metal pin. Mr. Converse spoke about the method of testing insulators, which was to use a salt-water solution. I would like to ask him if there are any reasons why, after an insulator is tested until the arc goes clear around, and is held there for a few seconds and there is no breakdown, that is not as good a test as putting it in salt water?

MR. CONVERSE: The salt water being a conductor, it serves to make connection all around the head of the insulator, and all around in the thread where the pin goes, thus giving a much better contact than could be obtained with metal. Also, in the case of a porcelain insulator, if there are any cracks or flaws, or if there is any tendency to absorb moisture, the salt water will percolate through and expose the defects.

Sig. F. CARINI: In answer to question of Mr. E. Kilburn Scott about the brown glaze insulators, there is a difference between brown glaze and white glaze insulators, namely, the brown-glaze insulators are usually made of common stoneware, and only have a very thin layer of glaze composed of silicate of soda, produced by the decomposition of salt, whilst the white porcelain has a very thick layer of silicate of alumina and lime. Concerning the wooden or iron pin, we have always used iron pins

in Italy, having never had any occasion to use, or to ask for, wooden pins, and are quite satisfied with our iron pins. As to attaching the iron and the porcelain, we have tried the lead cap; we cement a thin copper cap inside of the insulator, and this system has been lately patented throughout the world. I want to ask of Mr. Gerry, what is the coefficient of safety he would suggest for insulators? I mean, for instance, at what voltage should an insulator, meant to withstand 20,000 volts on the line, be tested?

MR. GERRY: That is always a matter of engineering judgment. The higher the better. At the present time insulators may be obtained having a factor of safety of from two to three, but as the art advances it will undoubtedly be desirable to use a much higher factor.

Mr. T. J. CREAGHEAD: In answer to Mr. Kilburn Scott in regard to the fastening of iron pins to insulators, I would say that I have had some little experience in that connection, from one point of view only — not in the operation, but in the design and manufacture of the pins. In that experience we have used two methods, one of which is very common and the other not so common. In the case of a malleable iron pin attached to the cross-arm by means of a steel stud, we have put a little enlargement on the head of the malleable iron, and fastened this malleable pin into the insulator by means of a lead compound, or by means of cement. In the other case, which is a little less frequent and one we look upon with a little more favor, there is a malleable iron pin, which has a specially designed wooden head. The particular size I have in mind runs about 8½ inches above the top of the cross-arm. The malleable casting is made about 9/16-inch in diameter and it has an enlargement on the head with a thread cut upon it. We screw upon that a wooden thimble, in some cases treated with oil or paraffine. It is screwed down on this enlarged head, and that acts as a cushion for the portion of the glass or insulator. As to mechanical tests, we find that this insulator will break with about 1000 pounds of side stress, which we look upon as very satisfactory. A side stress of a thousand pounds per wire is as much as the ordinary pole-line, properly guyed, will stand.

Secretary BELL: The hour of adjournment is now slightly overdue, so that we will hold any further discussion that there may be on this paper Friday morning, at which time will be taken up the paper by Messrs. Kelly and Bunker. Upon motion, the Section adjourned.

FRIDAY MORNING SESSION, SEPTEMBER 16.

CHAIRMAN SCOTT: The work of the morning will begin with the reading of the paper postponed from yesterday, that of Mr. Kelly and Mr. Bunker.

SOME DIFFICULTIES IN HIGH-TENSION TRANSMISSION AND METHODS MITIGATING THEM.

BY J. F. KELLY AND A. C. BUNKER.

In discussing the conditions which affect and limit the constants and operation of high-tension lines, pressures of over 30,000 volts and lines of over 50 miles in length only will be considered.

The usual relations between voltage and length of line, namely, "1000 volts per mile," or "the pressure in thousands of volts equals one-third the number of miles," cannot be applied generally until all sources of interruptions are taken into account, so that the length of transmission does not altogether determine the voltage to be used, for a voltage as high as possible will be used and its value be determined from local and climatic conditions.

These will be the principal factors in the design of any line, as all the other constants, except, perhaps, the kind of conductor, are interdependent upon them. Since there is always some doubt as to the successful maximum operating voltage which these conditions will permit, and just how the line will be affected, it is well so to design the step-up and step-down apparatus that, without seriously affecting its capacity, several voltages, say 30, 40, 50, and 60 kilovolts, or even higher, can be obtained at will. This arrangement will permit the power to be transmitted with the highest possible voltage, and the causes which prevent the use of the next higher pressure can be studied and overcome if possible. As a new plant is usually started with a load less than its capacity, there will be no serious decrease in the efficiency by this method of experimenting.

The principal causes of interruption of the supply of power in the past and at the present time are: Open-circuit, grounds, short-circuits, and other circuit changes which produce oscillations.

These are directly and indirectly traceable to weak insulators, lightning, defective pins, burning of poles at the ground, storms, and to a class which might be called unexpected sources. All the above may not be common to one locality, but all may exist on a single system. It may be said that where the quality and design of the apparatus and accessories for the generating and sub-stations have been selected with regard to their requirements, and where such are afterward intelligently handled, almost the entire list of troubles which are at the present time affecting the continuity of power service, may be credited to the line.

In designing a transmission line, experience has shown that the most careful study of local and climatic conditions should be made in order that all the facts and data bearing on these and their probable effects may be obtained.

It has been demonstrated that one transmission line for voltages over 30,000 will not give continuous service except when ideal climatic conditions exist. There is one, and possibly two, plants that have given continuous service for more than a year, with two circuits each, and with climatic conditions better than generally exist. It is believed that, in some localities, even with duplicate lines, the best insulators obtainable at present, and with perfect circuit-breakers, the maximum voltage which would permit continuous operation or delivery of power would be 40,000 volts, or possibly 50,000 volts with the utmost care and diligence.

The selection of the line-insulators depends entirely upon the voltage, mechanical strength required, and the localities through which the line passes, more particularly the latter, as lines have been operated at 45,000 volts with two or three types and sizes of insulators in as many different sections. The design of the insulators should be such as to give the smallest amount of still-air space and the greatest accessibility for wiping by hand. Fog occurring at the same time or intermittent with soil, factory, or car-dust is one of the surest causes of trouble, and reduces probably, to the greatest extent, the effective commercial size and value of insulators. Upon examining a large number of insulators which had to be removed, it was found that the dust, with which they were coated, was thickest in the still-air spaces, and was as thick on the vertical as on the horizontal surfaces. It has been found that where insulators were subjected to fogs or dust alone (except sea-fog), the same number of troubles did not occur as when both appeared together. Where insulators are covered with dust parts

of each year, it has been necessary to shut down the circuit from one to three times during the dust season to wipe them clean. This can be done while in position and without disturbing them unless they are found to be damaged.

The fact that insulators are successfully tested for high voltage before they are put up does not necessarily prove that they will not cause any trouble when on the line. Insulators which were tested for 120,000 volts water test for one minute have given trouble in less than a month after being placed on a 40,000-volt line. Other types which had stood 40,000 volts water test for five minutes have been known to be unsatisfactory for 13,000-volt city (overhead) service, though this would not hold in every city. The greatest value of electrical test for insulators before being used is to determine whether the various parts are homogeneous and whether they have been properly cemented together.

If an insulator was made up of three separate pieces, each having been tested for say 80,000 volts before cementing, it does not follow that the completed insulator will stand 240,000 volts or even 120,000 volts. The striking distance of the completed insulator, together with the quality and manner of cementing, determines very largely the final test voltage, even though they have sufficient creeping surface for a higher voltage.

In cementing a large number of insulators together, it was noted that the percentage broken down under test could be reduced almost one-half by a little more care in the method of cementing. When insulators are glazed together at the factory, a uniform insulator should be obtained. The conditions for transmission are very good, if, for continuous use, 1 per cent of the insulators does not have to be replaced each year. Taking a circuit having 12,000 insulators installed, there would be at least 120 renewals each year. Each poor insulator is liable to cause a disturbance or interruption, and the system might be subjected to an average of 10 per month.

If some seasons of the year are more severe on insulators than others, there may be more than 30 cases of trouble per month. It has been observed that, where insulators were giving trouble on a line operating at 40,000 volts, reducing the pressure to 30,000 volts did not produce a like or immediate decrease in the number of insulators broken per month. The total number remaining seemed to be in a more or less weakened condition, and would

continue to break down after the line-pressure was reduced, though after a certain period of time, the breakage per month was less.

The difficulties of taking care of lightning discharges increase much more rapidly than the line-pressure, for the reason that any disturbance or change in circuit conditions, produced by getting rid of, or dissipating, a charge in a circuit having high voltage and high inductive and capacity reactances, may set up oscillations which, if not serious to apparatus, are disastrous to regulation and service. Various combinations and multiples of low-voltage types of arresters have been used, but where these have not had the proper addition of a resistance, they have seldom failed to be completely destroyed when the particular stroke or circuit change occurred. It has been clearly shown that the same arrester could not, without special adjustments, be used on all parts of the circuit, and that arresters performing their function for a lightning stroke, or taking the kick-back from a short-circuit opening, when a given number of generators, length of line, or transformers were in circuit, would not so operate for another number of generators, transformers, or length of line. This may have been due to the increased inductance in circuit obtained from a smaller number of generators or transformers, to a longer length of line, to the nature and duration of the arc in opening the short-circuit, or to any number together of these conditions. Where a resistance is used with any type of arrester, in order to keep the value of current which would flow over the arresters, to a given percentage of the load-current, the amount should be such that five or six times the normal impressed voltage can be taken care of.

A modified form of the Siemens' arrester has been used on circuits up to 50,000 volts with a fair degree of success when they were correctly adjusted for the different positions of the circuit, and, where a resistance was placed in series, the voltmeter cards were not painted badly when lightning or a short-circuit occurred. This design can be greatly improved, and no doubt would give very good results and thoroughly protect connected transformers. Their low cost, ease of construction, and their outdoor serviceability are points in their favor.

Perhaps the most reliable arrester is one consisting of an inductance and condensance in parallel, so that any frequency variation from the normal would cause a certain value of current to flow. This type, immersed in oil, would be rugged, and could easily be adjusted for any position of the circuit.

One of the best means of dissipating an induced charge or stored energy in a line is by having a distributed load along the circuit. If this load has a grounded neutral, the effect of a lightning stroke will be greatly reduced and more easily taken care of by the regular arresters. The star-connected line with grounded neutral has, however, some disadvantages of equal importance, which should be carefully considered before being adopted.

In practice, next to troubles from lightning, short-circuits on long lines of low ohmic and high inductive and condensive reactances produce the most serious consequences. It is, therefore, necessary to use accessory apparatus which will discharge the circuit between wires, as well as between circuit and ground. This point should not be lost sight of in the selection of arresters, and in their connection to the circuit. When a line is short-circuited from any cause, there is a rush of current, the value of which depends upon the impressed voltage and the impedance of the circuit up to the point of the short-circuit. When this current is suddenly interrupted, the voltage induced depends upon the constants of the circuit and increases in value with the length of circuit, distance between wires, the amount of inductance of the connected apparatus, the inductance of the rupturing arc and its duration, the impressed voltage, and the instantaneous value of the current when the short-circuit is opened. This induced voltage will be small or of little importance if the short-circuit is opened at or near the zero value of the current. In operation, induced voltages have been observed when opening a 40,000-volt 100-mile line when short-circuited, of from 2½ to 6 times the normal voltage, as measured by the length of air-gap broken down by the kick-back. In the more severe cases, some point of the system usually suffers; that is, there will be a discharge or arc across some point of the line or transformer terminals, a puncturing of transformer coils, break-down of insulators, the destruction of lightning-arresters, or some other like effect. In nearly every case the circuit is put out of service unless efficient arresters are used. The fact that there is not more damage done than would seem likely from the voltages observed is, no doubt, due to the property of solid dielectrics of withstanding momentarily very high voltages and which would be punctured in an interval of time. Air having the property of breaking down immediately upon the application of the proper voltage for the gap is the

probable reason why these manifestations more commonly occur in air, from terminals, and around other dielectrics.

The troubles from the charring of wooden pins were due to the continual leakage of current over dust-coated insulators. In some localities, pins would last only from one to three months This was entirely corrected by placing a metal short-circuit around the pin. Molding at the thread, which is often noticed where the line passes through a marsh, can be prevented only by the use of a metal pin. Several lines have now been equipped with steel pins and no new troubles have developed, but, on the contrary, a decided decrease. It would seem that for large high-pressure lines steel pins should be used exclusively. Their initial cost is from one and a half times to twice the price of wooden pins, though cheaper in the end. Soft lead gives better results for the thread than any composition. The moulds should be made so that enough lead can be used to extend a little way below the bottom of the thread, as this will give a good bearing to the insulator over and above that obtained from the thread. This will greatly add to the mechanical strength of the insulator and of the line, as, with the ordinary pin, the insulator is the weakest element of the line. Precaution should be taken to have the thread portion short enough so as not to come in contact with the top of the insulator. This will prevent the tops being forced off when the insulators are put on the pins, and will allow a firm seat at the other end of the thread.

The service given by wooden pole-line construction is subjected to interruptions from falling and burning poles, due to decay, freshets, forest or grass fires, the large number of insulated points. and from the necessary short length of the poles. The decay of poles can be greatly lessened by continual inspection and care after they are up. The idea that poles of the right kind of wood for the soil can be placed in the ground and last for 10 or 20 years has been the cause of many and costly repairs. One 6-year-old redwood line, with butts treated before raising, had to have 33 per cent stubbs. Another redwood line, untreated, had to have 10 per cent stubbs in three years. Another line of untreated cedar poles required 35 per cent stubbs in six years. In long lines and even in some short ones, soils may be found that have an entirely different effect upon the life of the same wood.

Engineers are many times prevented from buying poles at the proper time to have them cut, on account of the interest charge

on the cost of the poles and erection, from the time the poles are paid for to the time when the wires are strung. The freight and hauling charges on from one-fourth to one-third more weight will offset a large amount of the interest charge. The result is that the poles are put in green and, unless they are afterward treated, decay will begin in a short time. If it is possible to obtain seasoned poles, their life will be much increased by thoroughly treating the butts before raising than by any subsequent single treatment. When green poles are used, no treatment should be given before raising, but the butts should be treated after the first dry season, and retreated every second or third season after, this depending upon the material used and condition in which the pole is found. There are on the market several kinds of treating material which are showing good results. This after-treatment consists in digging away the earth from the pole for about 18 ins. below ground-line and treating this surface, together with that 18 ins. above ground-line, after the decay and earth have been cleaned off. The old ground-line should then be changed by banking earth up around the pole. The cost of this treatment varies from $0.60 to $1.00 per pole, depending upon the location of the poles and the kind of material used.

At the same time the butts are treated, the pole-tops, gain cracks, and ends of the arms under the dead circuit should be painted. This is the best-known method whereby wooden construction, as a general thing, can be made to last the so-stated 20 or 25 years.

The burning of the poles at the ground has been the cause of interruptions even where the line was patroled twice a day, but the remedy is simply a question of persistence and expense in keeping the right of way cleared of all growth. It might be noted here that, even with a generous right of way kept cleared, the wind may carry the heat from a fire toward the line. Two cases are on record where the heat from a forest fire along a pole-line was not great enough to harm in any way the wood arms or poles, but did cause large numbers of glass insulators to crack and fall to the ground. Porcelain is less affected by heat than glass, and probably would not have caused as much breakage.

Some of the unexpected sources of trouble show how detailed must be the design and care of a line, and what insignificant and harmless-looking objects and occurrences may cause the complete shut-down of a circuit. After everything imaginable has been con-

sidered and provided for, there may still be accidents. One case is known where some dried hay was carried up into a 40,000-volt line, with the result that it was set on fire and produced an arc that shut off the power. The burning hay, being carried on by the wind, did considerable damage. On another line, a flock of pelicans flew into the telephone circuit which was strung several feet below the power wires. The span was something over 600 ft., with a sag of 19 ft. The telephone wires were struck so hard as to wrap them around the power-circuit.

Another case was where a long piece of light bark was blown several rods across a 42-in. line, with the usual result. On the same line, during one season, there were three interruptions, in one locality, caused by large birds getting across two of the wires.

The falling out of step of synchronous apparatus, while not frequent, does happen and, unless the breakers operate promptly, other apparatus may add to the trouble and the circuit be opened. On the other hand, with proper attention to field strengths, synchronous motors have several times been known to keep in step during temporary short-circuits on their connected direct-current generators, the direct-current breakers being purposely set at a high current or tied in.

The question as to whether wooden poles or steel towers should be used for a given transmission will be determined by the advantages of one over the other for the conditions to be met.

In countries where wooden poles are plentiful and inexpensive, it is probable that every expedient will be resorted to before steel towers are used.

One of the principal advantages of wooden construction is, that, in case an insulator is broken, allowing the wire to come against the arm or pole, the burning which takes place almost immediately in most cases may continue for several minutes before a blaze is started which will short the circuit. Several times it has been observed that from 20 to 30 minutes elapsed from the time trouble was first noted by the ammeters or telephone until it was necessary to shut off the circuit. In one case a 40,000-volt (grounded neutral) wire lay on a dry cross-arm for several hours before the circuit could be shut off, and at the end of the time the arm was not badly charred. With a duplicate line, ample time would in most cases be given for changing from one circuit to the other, or to cut out the affected circuit, providing the telephone line was operative or the men at both ends recognized the difficulty.

For the past four years, engineers have tried to adopt, where possible, steel towers, instead of wooden poles, as a means of correcting a large number of line troubles.

At first thought, towers would seem to solve all difficulties previously experienced and certainly do eliminate a great many. The spans can be increased, so that as few as eight towers per mile can be used with safety. This would greatly reduce the number of insulators which can be larger, and the means for their attachment to the towers can be quite elaborate without exceeding the cost of the other construction. The height of towers can be greater, which will decrease troubles from wires, branches, and other material being thrown or blown across the circuit and reduce the breakage of insulators from the heat of forest or grass fires. If galvanized, or painted, occasionally, their life would be greater than could be expected of wooden construction.

Towers can be erected in places even more difficult of access, since they can be taken apart in pieces of lighter weight than a wooden pole. They would offer a more or less good lightning path to ground which would help to prevent the injury to connected apparatus, but will no doubt subject each insulator to greater strains. Any leakage around, or puncturing of, an insulator will mean the immediate shut-down of the circuit, and, in order to prevent the shut-down of the entire system, overload and reverse circuit-breakers of the best possible design will have to be used.

Auxiliary insulation of sufficient mechanical strength could be used to reinforce the insulators carrying the conductors, as the towers would be able to carry considerably more weight than wooden poles for the same cost per mile.

The most economical design of a tower is not suitable for a good many places where the line would have to be erected, and could only be universally used on a private right of way. On railroad rights of way, narrow county roads, village streets, etc., the spreading base would not be allowed, and resort would have to be made to steel poles, which for the same strain and height would be more expensive.

The distance between wires is usually determined from the highest voltage which can reasonably be expected as a limit, as determined above. The rule that the distance between wires in inches equals one and one-half times the number of thousands of volts is safe so far as the striking, or repeating, distance is concerned, though to correct for arcs holding on for a time after once

established would be impossible. Where the cost of erected poles is high, or the right of way expensive, two circuits per pole-line should be used, and, with good wooden construction, mechanical difficulties would limit the distance between wires to at most 60 ins., which would allow a line voltage of say 50,000 or 60,000. This distance between wires is for spans not over 150 ft. to 200 ft. The size of wire is determined from the load, voltage, length of line, losses allowable, etc. Five per cent energy loss per 50 miles with 60-cycle frequency gives a line which can be taken care of, but a smaller loss should be obtained where important lighting service is had in connection with a fluctuating load. On account of the distance and pressure, a charging current, at no load, is required of the plant, which at 60 cycles and one line 100 miles long, or 30 cycles and two lines, would require a generator as large as 2000 kilowatts, so that, unless more than this capacity had to be delivered as load, the system would not be economical. In order to be perfectly flexible, this amount of power would have to be carried over one circuit. The wire would, therefore, be large enough for mechanical reasons, and the energy loss per insulator, or per unit length, would be negligible, except, perhaps, for voltages over 60,000.

There is one plant in operation which, if the energy loss per insulator, or unit length, was as much as calculated from experiments, it would not be able to deliver load.

In stringing the conductors, especially if they are of aluminum, attention must be given to the temperature at the time the wires are tied in. This might seem to many to be a useless and tedious process; but a set of curves showing the sags for given spans and temperatures, in the hands of a careful line foreman, will give a line good in appearance, and at all times safe from overstrains. It is not so important to know what the maximum sag for maximum temperature will be, as the maximum strain at lowest temperature, with sleet, if any, taken into account. Aluminum cables are made which are as strong as copper for the same conductivity. When conductors are given the proper sag, a given safe tension, can be maintained for longer spans than would ordinarily be used in transmission work. There are a number of spans over 600 ft. in length, and have been in operation for two or three years. These have been closely watched during wind-storms, to see what deflection would be given to the wires. Three aluminum cables 7/8 in. diameter, 600 ft. span, 19 ft. sag, were deflected from 30

degs. to 45 degs. from the vertical by a wind that was estimated to be 70 miles per hour. All three conductors kept their relative position when deflected, and there were no perceptible waves or vibrations in the cables.

It is claimed by some who have had the opportunity to notice, that in longer spans there is less tremor, vibrations, or waves passing over the span when there is a wind than when there is none.

All observations of the writers show that, for spans of 600 ft. at least, there is no tendency of the wires to swing together in ordinary storms. Tornadoes would no doubt twist the wires together, but that would not be the worst damage done.

The height of poles or towers would depend upon the sag and whether or not a telephone circuit was strung underneath. With spans of 660 ft., the sag for aluminum would be about 20 ft., and with a telephone circuit 6 ft. below, a 65-ft. tower would give a clearance below the telephone wires of 29 ft.

A clearance of 35 ft. below the lowest power-wires is little enough for places where a house or derrick is liable to be taken under.

The frequency to be adopted depends upon whether the power is to be supplied to already installed apparatus of a given frequency. For long lines, a frequency of over 60 cycles will give a regulation difficult to allow for. The lower the frequency, the better will be the regulation of a line for a given load, the smaller will be the generator capacity required to charge the line, and the voltage drop will more nearly approach the *IR* of the circuit. For a given line, there is only one particular value of current where the condensance of the line will be neutralized by the inductance;

Note.—It is frequently stated by some engineers that a three-phase circuit should be strung with the base of the equilateral triangle on top in order to prevent more than one-phase being shorted by wires being thrown over the circuit and in order that synchronous motors will continue to operate until they can be thrown on to another circuit.

If a sketch is made of either a star or delta circuit, and a wire shown across two of the circuit wires, it will be seen that two of the phases instead of one will be shorted, and that what remains is a modified single-phase, with varying constants depending upon the resistance and the swing of the shorting wire.

It has been observed, under the conditions, that a synchronous motor will, if carrying load, immediately fall out of step. For mechanical reasons, it would be better to place the apex at the top in order to reduce the pull from the pole top, and for electrical reasons, it would be as well, since the men in charge of the line cannot be present to select the kind and length of wire that is to be thrown over the circuit.

so that this fact also decreases in importance. The swing of the power-factor at the power-house will not be so great and the point of maximum power-factor will be nearer full load. For a new system, or where possible, over 30 cycles should not be used.

With the general use of A. C. railway motors, 15 cycles or less may be advisable.

The power-wires of a single- or double-circuit line should be transposed with reference to the power-taps and talking-points.

Experiment has shown that transpositions at stated distances need not be made and may not give as good results as the first method. With two circuits, one should be transposed in the opposite direction to the other; although there is one double-circuit line operating satisfactorily as far as the telephone is concerned, with one of the circuits run straight through. Experiments made with a power-line without transpositions and a telephone transposed every fifth mile placed 5 ft. below the power-wires, gave a pressure to ground of from 2100 volts to 2800 volts when the line-pressure was 40,000 volts. With 30,000 volts, the telephone voltage to ground was reduced in the same ratio.

By giving the power-wires two-thirds of a rotation between power-taps and talking-points, this voltage was not readable on a Weston or hot-wire 150-volt voltmeter. The induced voltage was due to capacity, and in none of the tests was there any measureable electromagnetically-induced voltage.

The large number of fatal accidents, which have occurred in the past from the telephone circuit being placed on the same poles with and under the power-wires, would warrant a separate pole-line, even if the service were no better.

A telephone is most needed at times of line disturbances, and at such times it is rarely of service. The induced voltage on a telephone circuit, even where power-line transpositions are made, when one or more of the power-wires are out or grounded, is high enough to be dangerous to life and to set fire to adjacent woodwork. The distance between the two circuits should be at least 6 ft., and 8 ft. would be better. In stringing the telephone wires, the same sag should be given as to the power-wires. For lines over 50 miles in length, copper or aluminum should be used instead of the regulation No. 9 BB.

The question of high-tension switches and circuit-breakers is one of the most important in the operation of a system. They should be of the most approved design only, and placed at both

ends of a circuit and at intermediate, or cross-over, points. All poles of a three-phase switch, or breaker, should work together and not singly. A switch which tests satisfactorily in the shop may not operate in service; so that it should be placed in position and opened 10 or more times under the most severe conditions with which it is likely to meet, before it is pronounced safe. All breakers and switches should be provided with cut-out switches on each side, so that they can be taken out of a *live* circuit for repairs.

Discussion.

Mr. Bunker: There was a statement made yesterday in the discussion that there was no ground for argument on the advantages of iron over wooden pins. There are some localities where wooden pins have no doubt been entirely successful; but as a general case, I would like to take exception to that statement, because there are plants now operating where they have a great deal of trouble with pins, and some of the pins only last from one to six months, until they begin to burn or mould, while in some cases they burn entirely off within that time. There was also another statement made that the burning of pins was due to the brush discharge and charging current of the pin. I suppose the charging current was due to the electrostatic capacity of the insulator itself. It was not stated what the brush discharge was due to, but if there was a brush discharge around the insulator it was either due to the fact that the insulator was not large enough for the voltage under normal conditions, or else that the insulator was covered with some dust or dirt. Now, in a given line, the pins are subjected to the same static pressure at all times. Some of them lasted two years and over, and have not been changed yet, being apparently as good as they ever were, while in other localities the pins have been changed as many as three times in one season. These were wooden pins, and I might say were made with as great care as possible. The sap was boiled out of them, and they were then treated in oil at about 100 degrees Centigrade, so that the insulation of the pin, when new, was perfect. You could subject a pin along its length to 60,000 volts without any effect and could leave it there as long as desired. The pins were of eucalyptus wood.

Mr. E. Kilburn Scott: When you say "burning," what do you mean?

Mr. Bunker: When you put an insulator on a line, using wooden pins, and everything is new and clean, there is no discharge or sound from it; but after it stands awhile, in certain sections you begin to hear a discharge, and if you watch the insulator at night, you will see, up in the thread portion underneath the inside petticoat, a discharge taking place. This gradually begins to burn the wood and after a while burns the pin entirely off at the bottom of the thread. Pin holes are at first made but after the char becomes general, it keeps getting deeper and deeper as a regular burn. There is only one remedy for moulding and that is a metal pin. I am not able to state what would take place where a line crosses a fresh-water marsh, but I do know in a salt-water marsh that a pin that

lasts six months is considered to be doing well. That rot or mould has a white appearance and is very soft. When you take the insulator off, you can very easily rub the threads off with your thumb. The treated pin appears to mould as rapidly as the untreated pin. The pins are treated with boiled linseed oil, after the sap is boiled out and drying, then being subjected to the hot oil, but not in a vacuum.

Dr. Louis Bell: In this suggestion of treating pins, I asked whether they were treated by vacuum treatment, and I regard that as of fundamental importance. You can boil even a thing so porous as a coil of wire, in insulating material,—for instance, melted paraffine—until you get black in the face and give up in despair, and then take it out and the insulation will not have thoroughly penetrated. Put that same coil of wire, in vacuo, in hot insulating material, and you see the gases rush out of the thing, and the whole surface of it foams for minutes. After that is over, the insulation has a chance to creep in. I therefore should ascribe some troubles to which Mr. Bunker refers, to the fact that although the pins were thoroughly treated, apparently, there was no small amount of material which the insulation did not fully penetrate, so that while it would hold the voltage for a while, the remaining air and moisture would sooner or later get in their work, the air helping the oxidation and the moisture gradually working itself through the structure. I should like to see the thing tried with pins which had been very carefully and thoroughly dried, to see whether the time effect would take place to the same degree.

Mr. Bunker: On the other hand, you take a metal pin and put it in the same locality and you would not have any trouble at all.

Dr. Bell: Save perhaps in puncturing the insulators. I approve of metal pins from a mechanical standpoint, but when we are fighting this high voltage I think if we can get any insulation strength below the main insulator on which we depend, we are so much better off in the desperate fight against creeping due to atmospheric moisture and to dirt accumulating on the insulator. If we could have a porcelain pole, in other words, we wouldn't have very much trouble in protecting insulators. The more insulating material we get in series, the lower potential gradient we have, and the less trouble we are likely to have. So that if it prove to be possible, as I hope it may, to use some absolutely non-metallic material for the pins, we shall be vastly better off than if carrying our ground to within an inch or half or three-quarters of an inch of sixty or eighty thousand volts. When we do that, we pin all our faith on the insulators, and insulators, as we see from this paper, sometimes fail; they do so much oftener than we like to have them.

Mr. E. Kilburn Scott: How would you stop the moulding of the pin?

Dr. Bell: I do not believe, with a properly designed insulator, the moulding of the pin, which is due largely to the brush discharge, as far as we have been able to ascertain, is going to take place, and I think in an iron-pin line, particularly with iron towers, you are depending too much on the insulator. Anything that happens to that insulator means just one thing—a complete shut-down, because you have grounded the whole circuit. As very properly noted here, you can have some troubles on a

wooden pole line without causing that. And while eventually we may, and probably will, use both steel pins and steel towers very largely, that being a matter which has to be treated symptomatically, still I do not believe that an attempt to get an insulating pin should be abandoned at the present time, and I do not think that with proper treatment of the pins, and with a properly designed insulator — in other words, an insulator which will hold back, as far as possible, the brush discharge — the matter of burning the pin, which in some places has been very serious, is going to take place to anything like the same extent. At least it is to be hoped so.

Mr. BUNKER: There is one thing I would again like to bring up in that connection, and that is that when the insulator and when the pin are new, when they are both clean, there is no brush discharge that you can detect, either by sight or sound; the brush discharge only occurs later on, as the insulator becomes coated with either fog or dust. And it has been my experience with all high-pressure discharges of a static nature, where they were produced from transformers, that they immediately set fire to combustible material.

DR. BELL: There is no doubt that treated wood has insulating properties of a fairly good quality. The question is whether they are permanent. With many transmission lines, they have been using pins under conditions which would lead one to expect trouble, and yet the trouble has not occurred. Of course, if the insulators are allowed to get dirty, you will get dynamic discharges anyhow, after a certain point, particularly if subjected to salt fog or anything of that kind. But it seems to me that throwing away the insulation of properly treated wood, is not a thing which should be done without due cause, and I do not think that the burning trouble has been sufficiently general as yet, to make one feel that it should be thrown away without any further attempt to improve the question of insulating the wooden pins. We have had wooden pins described on several lines — for instance, Mr. Gerry's — where they have been in absolutely successful use, as far as we can find out, and it strikes me that these brush discharges are due very largely to an imperfect design of insulator. Of course, where you have dust storms, as in the case of some of the plants west of us, which coat the insulator with mud, or with moisture which is more or less dusty, it is very hard to keep up the insulation in any way. But in the face of the fact that some of the very large high-voltage plants are using wooden pins successfully, it does seem to me that throwing up the game and depending on the insulation strength of insulators alone — which is great, of course, but still is subject to failure — is an unwise proceeding. I think we want to exhaust the possibilities of an insulating backing for our lines before we absolutely throw it aside. I hold no brief for wooden pins at all; am perfectly willing to use the steel ones when I can get them combined with insulators that will meet the requirements. But anything in the way of additional precaution seems to me justifiable.

Mr. N. J. NEALL: I should like to ask whether you have had any use of glass shields for pins?

MR. BUNKER: No, I have never had any experience with glass shields.

The only shield we did have was a small sleeve at the base of the pin. This cracked off, having simply allowed the dust to collect around the pin and prevented the rain cleaning it off.

Dr. Bell: The glass shield was practically a pretty deep petticoat that Mr. Gerry used, but it simply protects from these brush discharges. Under the existing working circumstances of the line there is no trouble from that cause. The pin and insulator, whether steel or wood, must be treated as a single structure. The support of the line depends on the electrical and mechanical strength of both those elements, and that is generally the weakest point in a line, from both standpoints. But it seems to me that Mr. Gerry's immunity from trouble with pins is to be ascribed to his very successful and careful insulator design more than anything else.

Mr. Bunker: I think it due to climatic conditions more than anything.

Secretary Bell: Possibly.

Mr. Neall: I think the insulator, mechanically, which Mr. Bunker has in line, would appear to you as being the same as Mr. Gerry's; because the latter has simply a sleeve on which the insulator rests, while the former has a long sleeve attached to the insulator and the space below this, where the pin could be exposed, has been covered with a small porcelain sleeve.

Mr. Bunker: They simply allowed the dust to get in, and there was no way to clean it out.

Dr. Bell: The absolute difference in experience between Mr. Gerry and yourself must have some basis. Both insulating systems were unquestionably built with skill and care. The difference may be purely climatic. The fact remains, however, that Mr. Gerry, on a very high-tension line, has been using wooden pins with complete success, so far as we can find out from him.

Mr. Bunker: The result to be obtained is the smallest number of shutdowns possible. Now, in a fog section we have had as many as twenty-six shutdowns in a month from broken insulators and wooden pins. We have changed as many as 600 wooden pins in a month. When we got on the steel pin the number of line troubles was greatly reduced. The voltage is 40,000, but even at 30,000 volts, if you can get better service with a steel pin, that is what you want to use.

Mr. N. A. Eckart: I would like to ask Dr. Bell if, with pins treated by the vacuum process, he would expect the trouble to arise from moisture still in the pin or due from outside conditions, from atmospheric conditions.

Dr. Bell: I should expect the trouble would largely come at first from the fact the insulating material had not worked thoroughly into the pin; in other words, had left it only partially filled. Second, from the fact that the presence of moisture and air remaining would gradually tend to damage the insulating material which had worked in. In other words, I shouldn't think it anything remarkable if some of the moisture, under stress of heat and cold and diffusion in time actually got through; so as to damage the insulating properties which had been obtained initially. I have never had any chance to compare, on a large scale the vacuum-treated pin with one that is merely boiled, but I know, from considerable experience in forcing insulation into material in general, including wood,

that the vacuum process is the only way of getting all the moist air out of the pin.

MR. BUNKER: There is another thing I would like to mention in regard to that point, and that is the burning and moulding takes place inside of the insulator above the lowest contact of the insulator with the wood, so that you get very little oxidation action from the air. In fact the greatest moulding is at the top of the pin.

DR. BELL: Mainly on the thread where the fibers are cut crosswise?

MR. BUNKER: Yes, but it is away from the air.

Secretary BELL: Well, partially away from the air.

MR. BUNKER: But at that point, the threads, of course, are the most saturated with oil.

Secretary BELL: May-be.

MR. BUNKER: There is no question of that. We sawed several pins through to see.

Chairman SCOTT: A gentleman who in recent construction has concentrated himself along the wooden idea, both in poles, pins, cross-arms, braces and everything else, so that everything is wood and no metal at all, is Mr. Nunn. If he can add something to our discussion now we will let him have the opportunity for a final word on this question.

Mr. P. N. NUNN: The experiences of the Telluride Power Company seem to show that wooden pins are all right when rightly treated. The 40,000-volt Utah transmission was put into service in 1897, when 16,000 was the highest voltage elsewhere used. This was an advance at one step from 16,000 to 40,000 volts,— nearly thrice. That transmission has now been in operation for seven years, has been entirely successful, and is in operation to-day. The same pins and insulators used at the start are still in use — paraffined locust pins and Provo type glass insulators. These have since been used everywhere, and in no known case have pins been burned or replaced, except on account of broken insulators or the severest salt storms. The insulator has been criticised in all quarters, and its undeniable success has been attributed to the paraffined pin. Now that pin is said to be bad. The Provo insulator is certainly inferior to those now generally used for 40,000 volts. It was designed in the day of 16,000 volts maximum. These later and better insulators represent the advance of seven years in insulator development. The Provo insulator was known to be inadequate to use with metal pins; hence they were used with wooden pins impregnated with paraffine by the following method, previously devised and since used:

Clear, straight-grained locust pins are stirred for six to twelve hours in vats of hot paraffine at 150° C. and then kept submerged during slow cooling. If the pins are green, the boiling must begin at a low temperature, be slowly raised, and be continued much longer than if dry; but no matter how dry they may be, water vapor will be freely liberated for some hours, this part of the treatment being little more than a method of kiln drying. While slowly cooling, however, the condensation of water vapor remaining in the wood provides a most perfect "vacuum process" which sucks in the still liquid paraffine. If a sliver be removed from the center of a pin treated in this manner, it will be found well filled with paraffine.

On one occasion during a severe storm following a long period of dry weather, partial grounds developed upon a section of line supplied with insulators from a certain shipment which had been improperly annealed. After the storm, over 50 broken insulators were removed, yet no interruption had occurred and few pins had been burned. According to the results of a laboratory test, published a few years ago by a prominent insulator manufacturer, the entire capacity of the Provo plant should not be sufficient to supply leakage current to half its lines in bad weather. Yet the facts are that leakage has never been appreciable. Wooden pins are said to burn with slightest leakage, yet brush discharge has rarely been visible, and then only when insulators and pins have been heavily coated by salt stoims, and no difficulty has been met from burned pins. These salt storms are believed to be as severe as any sea-coast spray, and it does not seem probable that serious trouble would be met upon the coast with properly paraffined wooden pins.

Mr. Bunker: Just one thing I would like to mention in regard to the last remark, and that is that where we removed several wooden pins we put the same insulators back onto the steel ones without experiencing any trouble. My argument in regard to the iron over the wooden pins is simply as a general case. I agree with you and Mr. Gerry that in a great many localities wooden pins are all that could be desired, but in other localities something else will have to be done, either in the treatment of the pin or the use of steel.

Mr. K. Landtmanson: I should like to ask if for all voltages wooden pins are used?

Chairman Scott: I think I am right in saying that both kinds of pins are used; that in general wooden pins in work that would be called transmission work; sometimes where the wires are heavy, iron pins are used. One difficulty with the pin on the higher voltage is that they need to be large and consequently the metal pin is especially desired on account of its strength, and in high-tension work the pole lines are out over the mountains and sometimes have longer spans, so that the difficulties of construction and inspection are greater than with the low-voltage lines which are not so long. I believe I am correct in saying that wooden pins are generally used for the lower voltage work where they can be used. That is the preference.

Mr. Landtmanson: If you have a line of, say 50,000 volts and if an insulator broke down, have you found danger from touching a pole? I have heard that a man has been killed who touched the wire with a wet ladder, and I think if we have, say, 50,000 volts between two wires, and if an insulator breaks down and the wire then touches the wooden pins, that the leakage can be so great that a man who touches a pole can be killed by it.

Mr. Nunn: No one has ever been seriously injured in that way. A few poles have been carbonized along a streak down one side throughout their length. Leakage can be determined by feeling the pole near its bottom.

Mr. E. Kilburn Scott: Where you have great depth of insulator, I think pins made of malleable iron are good; because they can be made

with a good broad base to rest on the cross-arm. They might also have a vitrified surface. I have seen many articles of steel or other metal furnished with quite a thick coat of glaze or enamel and they could be dropped on the ground without breaking the glaze. I should think the glaze might be of value from the standpoint of insulation. Regarding wooden pins, I think I can safely say that there is no such thing in all Europe. We are quite satisfied with steel pins; but then, of course, we do not have your very high pressures. As I may not have an opportunity of referring to it again, I may mention that in some of the British colonies, there is great trouble with the white ant. If, in such places, a wooden pole were to be placed in the ground, all the inside wood would be eaten away; indeed they would think nothing of invading the cross-arms. The poles must, therefore, be of iron, or be composite; i. e., have an iron socket in the ground, and only the upper portion of wood, as at Cauvery Falls. To give an idea of what the white ant is capable, there is a story of an Anglo-Indian official who left his house in India for some considerable time. The white ants penetrated the legs of a table, and after they had cleaned them out and the table top, they crawled up and ate the inside of the family bible. When the official returned, everything seemed all right until he laid something on the bible, when it went right through.

Mr. J. S. Peck: One thing struck me as rather interesting as showing the difference of opinion of eminent engineers on the same subject. Mr. Baum told us a couple of days ago that when you exceed 60,000 volts lightning protection need not be considered. Mr. Bunker says the difficulties due to lightning discharges increase much more rapidly than the line pressure. I would like to ask Mr. Bunker whether he has ever tried the arrangement he speaks of in his paper — that is, an inductance and condenser in parallel with the lightning arrester and air gaps?

Mr. Bunker: I should have stated that it has only been tried in laboratory experiments. That is Dr. Kelly's idea of an arrester, and it has never been put in practical operation. As regards lightning protection, when the voltage goes up, I think nearly everybody will agree that inasmuch as the impressed voltage is a function of your troubles, the trouble is going to increase. For instance, at 25,000 volts we would have very little trouble as compared with 40,000.

Mr. R. S. Hutton: I think the proper construction of Mr. Baum's remarks is, that as lightning arresters had given considerable trouble at 40,000 volts, if you attempted to go higher it would be harder to make a successful lightning arrester. We know we have lightning arresters that are quite successful at ten, fifteen, twenty thousand volts. Some may have been made that are giving good service on even higher voltage; but it stands to reason that when 40,000 give trouble, and considerable trouble, that if you go to 60,000 you are going to have more. Now, Mr. Baum meant this: That with the particular conditions which we have on the Pacific Coast, severe lightning is very infrequent, and as it does not bother us a great deal, it is not necessary to have any elaborate system of lightning arresters. Therefore, the horn arrester has practically answered the purpose. As we increase the insulation on our whole system, which is necessary to be done, of course, with increasing voltages, I think we shall have less trouble from lightning, but at the same time it

would be more difficult to make a lightning arrester to take care of it if you did attempt it.

MR. PECK: I think the point you made last was the thing he had in mind — that the lightning effect is, in a sense, constant and that the factor of safety which you have in a high-tension plant is such that the lightning effect, added to the normal pressure, is not sufficient to break down the system. At least that is the argument I thought he advanced.

MR. HUTTON: Mr. Baum stated the other day when his paper was being discussed, that no poles, to his knowledge, had ever been struck by lightning. Just before Mr. Baum was connected with the company, the Sacramento-Colgate line was struck about ten miles, I think it was, from our sub-station. The transformers were connected at the time at both ends on the high-tension side, but the low-tension sides were cut out and the line was not being used. Two poles were completely destroyed. The line is run along a county road which is fenced off with barbed wire, and it tore all the posts to pieces in the span between the two poles and pretty nearly consumed the barbed wire, but the line wires on the pole and the insulators were uninjured. The cross-arms were all split to pieces and lay in a tangled mass, about half up the pole. There was not the slightest kind of a burn on the line wire. Nobody knew anything about it until we tried to put current on the line. As the wires were together in contact, they did not get any chance to burn from an arc and when we sent a man out he found this mess.

MR. E. KILBURN SCOTT: Of course, the inside of the metal socket pole I referred to just now is filled with concrete. White ants never crawl outside of anything. Another difficulty which has to be considered in the East is the monkey difficulty. In some cases these animals will climb up the poles, and the only way to prevent them is to wind barbed wire around the poles. The ordinary spiked ring which deters a small boy or a native is of no use with a monkey. Perhaps some day we may be able to print danger notices in the Simian language.

MR. NEALL: Mr. Scott's remarks lead up to one conclusion that I think has been lost sight of, and it is this: If we could depend absolutely on the insulator, and use metal pole construction throughout, we should then know exactly the weak points of the line, and by making due allowance for the insulators and their effect on the line — such for example as their capacity effects at times of line disturbances — we could anticipate the troubles more closely and consequently have better service.

MR. NUNN: Without doubt metal pins will eventually be used with each successive transmission voltage, but they should be used only when that voltage and its insulator have passed their experimental stage. In pioneer work insulators are always likely to be worked to a very close margin, and then they should be supplemented with treated wooden pins.

CHAIRMAN SCOTT: In the remarks Mr. Nunn has just made he has struck the key-note of transmission work as it has been in the past, and while we are apt sometimes to consider that things are pretty well established, the same word I think will apply for many years to come — pioneer work. As we branch into new fields of high-voltage work, we encounter new experiences; new things, as well as matters which were of no

concern before, come up to the first rank in importance. Take our whole discussion this morning and what has it been? It has been on the insulator pin, a thing which a man not familiar with the subject would think one of least consequence, but we have found that it is one of the vital points; that the different methods of construction and treatment, and the experience which in one place and by one man differs in many ways from those of others. Now, one of the pioneers in this work, a man who has already said in his remarks a few minutes ago what I intended to say at this time, a man who went ahead years ago and used a voltage three times that which was in common use, which sounded higher in those days than a hundred thousand volts sounds now, a man who went ahead with a plant of that kind and has made it work, and has been one of the leaders in power transmission work in the West, is Mr. Nunn. So far as I know, Mr. Nunn has never been before a technical society before with a paper on this or any other subject. I think that we are especially to be congratulated on having Mr. Nunn at this time present a history of this pioneer work. This Congress ought to deal somewhat with the past as well as the present and future.

MR. BUNKER (*communicated after adjournment*): There seems to be a prevailing idea among many engineers that a rainy or a wet season is something to be feared in the operation of a high-tension line. As a matter of fact, experience has shown that fewer line troubles occur in a wet than in a prolonged dry season, due to the cleaning effect of the rains. Forty to fifty thousand volts have been thrown during heavy rains onto long stretches of dead line with no more disturbance than under normal conditions. The first rain, however, after a duration of dry or dusty weather which has permitted the insulators to be covered with dirt, causes increased leakage due to the mud formed. With proper insulators, a wet season is to be preferred to a drought, so that wet pins have not actually proven to be a disadvantage.

A further cause of the burning of wooden pins other than leakage, is due to the fact that when the insulators are coated with a more or less conducting material, they become condensers of greater or less capacity which reduces the value of the pin as an insulator. The small contact area of the insulator with the pins, increases the density of current flow to an extent which produces heat enough to char the wood. Where this contact area is increased by using a metal pin, or a metal short around the wood pin no burning takes place. The use of insulating materials of various values in series has the same effect here as in other places, where it is more commonly known and breaks, or tends to break down, the insulation having the least dielectric strength. These small insulator condensers simply add to the capacity of the system, and if the small condenser currents can be prevented from causing burning action as by the use of metal connections to the supports, the insulation of the line is thrown back where it belongs, namely to the insulator.

MR. P. N. NUNN then read a paper on "Pioneer Work of the Telluride Power Company."

PIONEER WORK OF THE TELLURIDE POWER COMPANY.

BY P. N. NUNN.

During the winter of 1890, the year preceding the famous Frankfort-Lauffen experiment, apparatus was installed for the first commercial, high-pressure, alternating-current power transmission of the world. From that beginning has grown The Telluride Power Company.

The mining district surrounding Telluride, San Miguel county, Colo., is at the same time one of the most rugged and one of the richest in the Rocky Mountains; but its inaccessibility and the consequent cost of producing power caused the financial failure of many important enterprises in the early days of its history. The statement made in the Annual Report of the Treasury of the United States, in 1901,[1] that "For the growth of its mining industry, San Miguel county is indebted to the Telluride Power Transmission Company more than to any other agency," is borne out by the fact that at the present time all of the important mines and mills of the district are operated by power furnished by this company.

The Gold King mill, situated at an altitude of 12,000 ft., where the cost of fuel for steam power had become prohibitive, was the first to be operated by means of this power. This property had been attached in 1888 to satisfy a continued deficit in operations. Mr. L. L. Nunn, the attorney retained by the owners, found that this deficit was largely due to the enormous cost of power, and that there would have been a handsome margin if power could have been furnished at not more than $100 per hp-year. Down in a deep gorge of the valley, over 2000 ft. lower, but less than three miles away, two mountain streams formed at their confluence the South Fork of the San Miguel river, offering cheap and continuous power. A stay of proceedings was secured; and, as a means of transmitting this power, cable drive, compressed air and continuous-current elec-

1. Annual Reports of the Treasury of the United States. Report of the Director of the Mint, page 135.

tricity were all investigated. The limitations of each were apparent, while the advantages of alternating current and higher pressures became gradually recognized, and a decision was reached to attempt their use. This decision was due less to the immediate saving in copper, than to a keen sense of the limitation of continuous current, and faith in the final success and ultimate superiority of alternating current.

During the investigation which followed and while selecting apparatus, little but incredulity or ridicule was encountered. Eastern investors in the enterprise were annoyed by predictions of prominent engineers, and discouraged by their insistence, that the experiment would prove a miserable failure and the expenditure go for naught. It was said that there was no alternating-current motor; that oil insulators must be used, and that the line must be fenced in. However, a generator and a motor for 3000 volts and of 100 hp. each were ready for trial in the fall of 1890. Difficulties caused by ice at 40 deg. below zero, by speed control over unusually high water pressure, by avalanche, by blizzard, by electric storms unknown in low altitudes, and many other troubles, now generally forgotten, but then most serious, marked every step of progress. Notwithstanding all of these, unqualified success from the beginning caused gradual and constant growth, until at the present time the Telluride company and its allied industries have six power stations and nearly a thousand miles of line in Colorado, Utah, and Montana.

Following its pioneer power transmission, it made practical experiments as early as 1895 with pressures which have never, even yet, been exceeded, and for three years it operated commercially the highest pressure transmission of the world. Thus the record of its work becomes an important chapter in the history of power transmission; but it must readily be seen that the limit of this paper precludes the possibility of describing all, or even a substantial part, of its pioneer work.

The initial installation, purchased through Mr. F. B. H. Paine, comprised a generator installed in a rough cabin upon the site of the present Ames station and belted to a 6-ft. Pelton wheel under 320 feet head, and a motor at the mill 2.6 miles distant. The two were identical Westinghouse single-phase alternators of 100 horse-power, the largest then made. The generator was separately excited, while the motor was self-exciting. Each carried a 12-part commutator and was slightly compounded through current

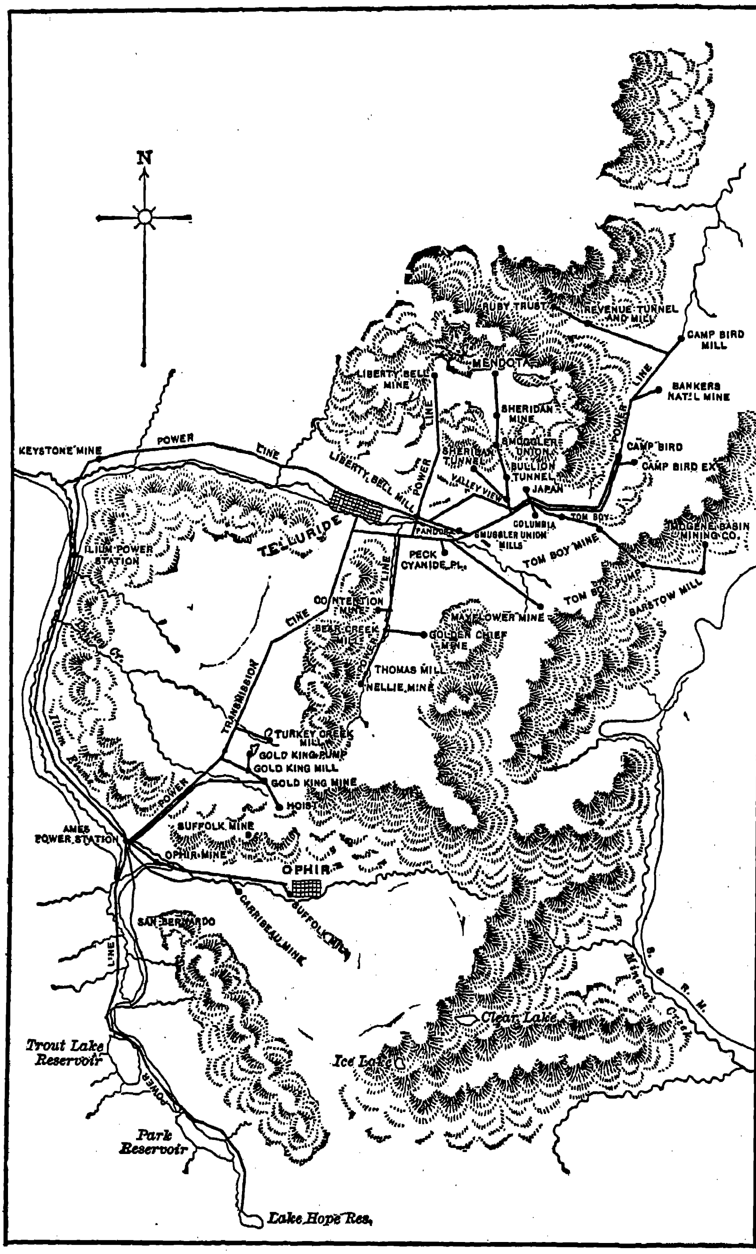


FIG. 1.—MAP OF TELLURIDE DISTRICT, SHOWING SYSTEM OF RESERVOIRS, WATERWAYS AND POWER-HOUSES, TRANSMISSION AND DISTRIBUTION LINES.

transformers upon opposite spokes of the armature. The latter were ironclad or "T"-toothed, wound with 12 simple coils in cells of fullerboard and mica. Switchboards were matched and shellaced pine sheathing, and the bases of instruments were dry hard wood. Only voltmeters and ammeters were used, both of the solenoid and gravity-balance type, in black-walnut cases with window-glass fronts. Circuits were closed with jaw switches and opened by arc-light plugs. The line carried two No. 3 bare copper wires, mounted upon short Western Union cross-arms and insulators. The copper cost about $700, or about 1 per cent of the estimated cost for continuous current.

The main motor was brought to synchronous speed by a single-phase induction starting motor, which received its current at full line voltage. The current taken was more than full-load current of the main motor. This starting motor, even, required starting by hand, its torque being zero at starting, and so feeble at low speeds that when cold it could only with the greatest difficulty be persuaded to pull up to speed its belt and loose pulley. Nor could it at speed start the main motor without help, and even then it became so hot that its short-circuited secondary frequently burned out.

Another motor of 50 horse-power was soon added. While in other respects similar to the first, this motor was intended to be self-starting, with armature and field in series through a current transformer; and on account of its frightful flashing, it was fitted with a special eight-part commutator of non-arcing metal. This feature, however, proving a failure, was soon replaced by a separate starter.

The need of a wattmeter or power-factor indicator not having been at that time recognized, the motor field charge was adjusted for least main current. This current was accepted as having unity power factor, and, therefore, as the measure of actual power.

Everything was extremely simple from water wheels to motors; and, except for lightning, the plant ran smoothly and steadily 30 days and more without a stop. The report made in the East by associates of the enterprise that at Telluride 100 horse-power was being successfully transmitted nearly three miles over No. 3 copper, wires with less than 5 per cent loss, was received with the utmost incredulity.

During the autumn of 1892, a 600-hp generator of the same characteristics was installed, and a 250-hp motor for the mill on Bear Creek, 10 miles from the generator. Early in 1894, a 50-hp, and during the fall, a 75-hp motor were placed in Savage Basin, 14

miles from the power-house. The former was soon replaced by a 100-hp motor, and in 1895 a 100-hp motor was set up at Pandora.

Except as to size these motors were substantially identical. The 250-hp motor was badly designed, and the pole pieces were of cast-iron. Its starting motor was insufficient, and was, therefore, soon replaced by one having split-phase secondary with extěrnal resistances. Marble with brass trimmings replaced wooden-base instruments, and such elegance demanded highly-polished slat switchboards of paraffined oak. Imposing marble rheostats were mounted at switchboards like keyboards upon grand organs. Fuse blocks, the only protective device, became marble slabs with duplicate aluminum strips. The first synchrophone came with the 75-hp equipment.

Owing to its altitude and geographic position, the Telluride district is peculiarly subject to atmospheric disturbances. Over 100 distinct discharges have been counted within a single hour, and lightning caused more discouragement than any other obstacle. A neighboring continuous-current plant, transmitting a little more than a mile, carried several extra armatures; and even then it was so frequently compelled to close down during the daily storms of the rainy season, that the company was eventually bankrupted. The alternating plant might have suffered a similar fate had it not been for its "T"-toothed armatures and replaceable coils, eight of which were successively burned out and replaced on one motor within a single week. To get a coil into place, and its oak keys driven home, required such bending, clamping, and pounding as inevitably resulted in injury to insulation, and only by the greatest care could replaced coils be made to stand a test adequate to the 3000 volts employed. For protection from lightning, several types of manufactured arresters, then various original devices were tried, ending with a simple gap in series with a score or more of fuse blocks in parallel, arranged about a radial commutator switch, turned from point to point as the fuses were blown by successive discharges. From the first these conditions caused the greatest apprehension as to the commercial success of electric-power transmission, until Mr. Alexander J. Wurts, during a stay of several months with the company, gave the protection of the now well-known non-arcing arrester.

No transformers were used between machines and line, the largest transformers at first being 2-kw, or 40-light. Aside from the effects of lightning, even to-day 3000 volts upon the winding of small high-speed armatures requires first-class insulation. Frequent grounds

were prevented by deep insulating foundations of paraffined wood. To prevent short-circuits within the coils, their cells, just before placing, were poured full of shellac, and the entire armature afterward baked for several days. By this means the 50-hp motor ran a full year without trouble in a room dripping with moisture

A lighting transformer received in 1891 was rated at 5 kilowatts. Theretofore transformers had been rated in lights, and generators in horse-power. This transformer was immersed in engine oil, and marks an epoch in the company's history. Lightning frequently punctured it, causing its fuses to blow, but without other apparent injury. It remained in service for years. All others were soon likewise immersed. Four 500-light, dry Stanley transformers, purchased in 1892 for lighting Telluride, were broken down by the thunder storms of the following spring. When repaired these also were immersed in engine oil, and gave no further trouble during the three years they remained in service.

Alternators were paralleled at Telluride in the spring of 1893, and thereafter they were so operated with full load upon the smaller and regulation upon the larger machine.

Manipulation at switchboards or at brushes involved direct handling of 3000 volts, a rather high switchboard pressure even now. It was a rule that every attendant keep one hand in his pocket while working with the other. It is pleasant to record that during these years no loss of life and but few accidents occurred.

There being no other circuit-breakers, it was necessary, when a motor dropped out of step, to break the circuit with the single arc-light plug. This always drew a heavy, vicious arc, which on the big motor frequently held to the full length of the 6-ft. cable, and then sometimes required a whiff from the attendant's hat. When not broken promptly it frequently involved the entire switchboard and shut down the plant.

Duties of this nature required considerable skill and cool heads, and in order to operate the plant continuously, night and day, 15 or 20 competent attendants were required. To fit young men for these positions a course was arranged during which they were taught something of machinery, of shop-work in metal and wood, and of wiring, insulating, and repairing, while receiving such assistance in daily study as conditions permitted. A technical library, including the electrical papers, and a conveniently-fitted testing-room were always open. Each student was then given a short laboratory course

in graphic treatment of alternating-current theory. This is said to have been the first systematic effort made by a corporation to train its employees for responsible positions.

Although the plant as a whole was an unqualified commercial success, no explanation need here be made as to why it was replaced by the induction system as soon as the latter had been perfected. This marks the limit of the most extensive single-phase, synchronous plant ever operated. With but one or two motors its operation was not difficult; but each motor added to the system brought increased demand for care and skill. The causes of difficulty were not understood then as now, nor was the effect of power factor fully appreciated. Lack of both wattmeters and power-factor indicators left the adjustment of field charges to the judgment of the operators. The power factor of each motor being dependent not only upon its own adjustment but upon that of all, the closest attention and co-operation were necessary, in marked contrast with the simplicity of operation of induction motors. Disturbances due to starting motors were especially trying; and the unqualified success attained, notwithstanding defects of apparatus and system, is attributed now, far more than then, to the skill and vigilance of the operators in this new and fascinating field.

The Tesla system, substituted for the synchronous in 1896, comprised two 600-kw, 60-cycle, 500-volt, two-phase generators, direct connected to wheels under 600 and 900 feet head, respectively, and an equal capacity of raising and reducing transformers and of two-phase, 220-volt induction motors. The 12 100-kw, step-up transformers were connected in pairs, two-phase—three-phase, for three-phase, 10,000-volt transmission. These transformers were worthless; all broke down within a year, and one or more were always undergoing repairs. Break-downs occasionally caused sufficient explosion to lift a cover, or splash the oil. The woodwork soon became saturated, and hot metal from the near-by main fuses frequently started fires, endangering the wooden power-house. A masonry transformer-house in two compartments was, therefore, constructed, and into it the transformers were moved,—this being the first known case of isolation of oil transformers on account of fire risk.

The power-house at Ilium, situated six miles below Ames on the same stream and using the same water, was built in 1900, and contains one 1200-kw, revolving-field, General Electric generator, di-

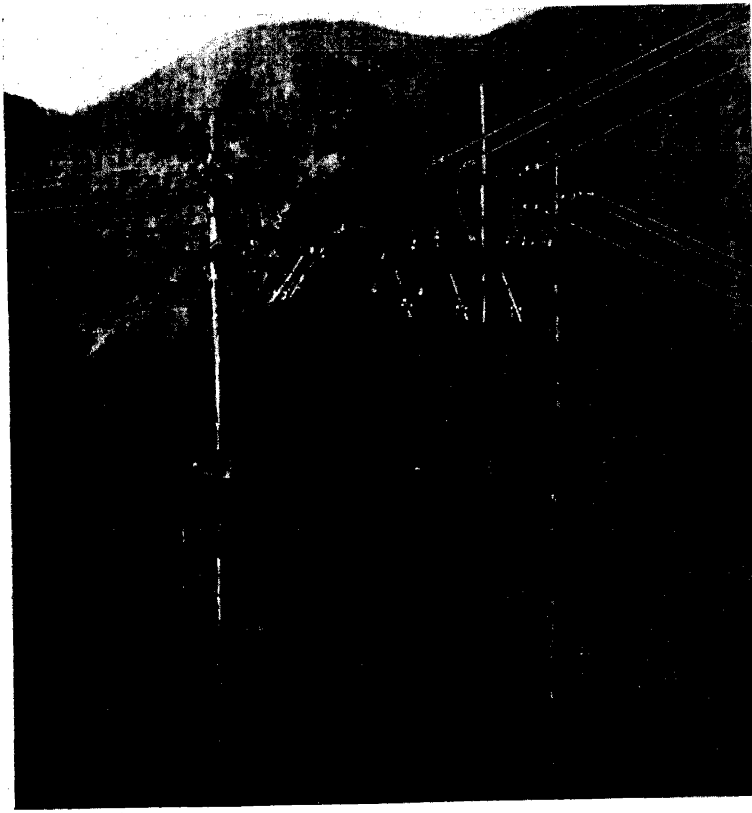


FIG. 2.—AN OPEN-AIR SWITCHING JUNCTION.

FIG. 3.—TOWER ON SUMMIT OF CAMP BIRD DIVIDE.

rect connected to two impulse wheels under 500 feet head. Transmission lines extend both to the Ames station and to points of distribution, providing the insurance of duplicate transmission. Any section of line can be cut out for repair, or either power-house shut down, without interrupting the service. Junctions, other than generating and distributing points, are equipped with open-air switches, mounted upon standard line insulators and operated from platforms similarly insulated, and have proven invaluable.

Junction-houses at distributing centers provide for a branch line to each customer, which is equipped with switches, fuses, and a set of five record-making instruments — a voltmeter, 2 ammeters, and 2 wattmeters. The power company thus secures upon its own property a continuous, accurate, and satisfactory record of each load.

The long spans crossing canyons and divides surrounding Savage Basin may be worthy of note. These divides are bare ridges at an altitude of 13,000 ft., inaccessible in winter and swept by frequent snow slides. Spans up to 1150 ft. are used in order to reach safe points for supports. A number of these supports, although simple and inexpensive, have stood for years without repair. The longest span is of No. 1, hard-drawn copper, supported by $\frac{1}{2}$-in. plow-steel cable, both being carried by the same insulators. The deflection is approximately 35 ft. on a slope of 31 deg. Another is of $\frac{3}{8}$-in. soft-iron cable 1120 ft. long, and has been in service five years. A third, 660 ft. long, is of hard-drawn copper only, having 25 ft. deflection. The strain insulators in all cases are a series of the usual line insulators and pins upon a longitudinal arm hinged to permit adjustment to span motion. They are simple, inexpensive, and entirely successful.

A 10,000-volt, underground transmission was put in operation at the Gold King mine in 1896. Power was carried through an unused tunnel 1300 ft. long, upon bare copper conductors 12 in. apart on standard line insulators, to a deep mining hoist equipped for electric power. The tunnel was always dripping with water, but no trouble was experienced during the several years of operation, although slight brush discharge or halo was at times observed.

An interesting installation to which power is furnished is that of the well-known Camp Bird, Limited, near Ouray. Nineteen motors and rotaries, in sizes up to 150 kilowatts, drive crushers, Huntingtons, concentrators, compressors, pumps, and hoists, aggregating in all about 1000 kilowatts. Two underground transmis-

sions, each a mile in extent, are in operation. Continuous current at 550 volts from two rotaries and a 650-ampere-hour storage battery operate three deep-mine hoists of 150 horse-power, and an installation designed by Mr. C. S. Ruffner, now engineer of the Utah department, makes use of the alternating current transmitted at 10,000 volts through paper-insulated, lead-covered cable, for the purpose of operating two 50-hp pumps.

The success of the original plant prompted the manager of the company, Mr. L. L. Nunn, to institute a search for other water powers in the West, finding as a result that such powers were very remote from available markets, requiring much longer transmissions than theretofore used. Voltages higher than from 10,000 to 15,000 were not in commercial use, and were regarded as merely problematical; but two important water rights, already acquired in Utah and Montana, would have been worthless at such pressures. Mr. Nunn, therefore, determined in 1895 to undertake at Telluride an experimental transmission at higher voltages, to be installed and operated as a practical test for power purposes, and to determine, if possible, the problems peculiar to long distances and high pressures.

Two identical 75-kw, oil-insulated transformers were installed in the autumn of 1895, one at the Ames station and the other at the Gold King mill. They were designed for pressures varying from 15,000 to 60,000 volts by convenient steps. A separate pole line was equipped with three circuits of different characteristics, upon three types of insulators.

Measurements with many special instruments were made, embracing the different voltages, styles of insulators, conductors, and distances between them, and the conditions peculiar to the various phenomena met at every step. Observations upon a wide range of atmospheric conditions were made by means of United States Weather Bureau apparatus at either end of the line. The commercial feasibility of high pressures was demonstrated by the successful operation of the Gold King mill during a great part of the year at pressures from 30,000 to nearly 60,000 volts, as well as by continuous electrification for nearly a month during dry weather, of a three-mile telephone circuit upon telegraph insulators, at pressures rising from 10,000 to 40,000 volts.

The change of the system from single to polyphase terminated actual transmission experiments. The reducing transformer was moved to the station, and another equipment designed for polyphase

tests was ordered. The remaining time was devoted to open-circuit losses, and to the verification of measurements previously made. This work continued until August, 1897, when construction was begun upon the Provo plant.

Much of the data obtained from these experiments was incomplete, requiring caution in its use, due largely to the time and study required in solving, step by step, the problems and difficulties met at every stage of the work. However, that much of value was obtained is shown by the subsequent successes at Provo. Sufficient had been learned to warrant the commercial adoption for the first time of 40,000 volts,—nearly thrice the voltage of any previous plant; to lead to the manufacture of transformers which, after seven years' continuous operation, are still in daily service; to determine the design of the Provo-type insulator, the method of line construction, distance between wires, and the importance of wave form, and to make possible this great advance in long-distance, high-voltage transmission.

This experimental work, as clearly appears from the foregoing facts, was begun, carried on, and finally utilized by the Telluride company in the regular and necessary course of its growing business; yet it must be added that important services were rendered by Mr. V. G. Converse, under whose direction the transformers had been designed and constructed, and who participated throughout the greater part of the work during all the experiments with actual high-pressure transmission, and subsequently by Mr. Ralph D. Mershon in the elaborate instrumentation and laboratory practice, including a notably ingenious method of reading high-tension losses upon low-tension circuits, devised by him and used in substantiating the accuracy of the earlier measurements; also that different types of insulators were contributed by the General Electric and the Westinghouse companies and by Mr. Fred M. Locke on account of their friendly interest in the work.[2]

The original plant at Provo contained two 750-kw, 60-cycle, 800-volt, three-phase General Electric generators, direct connected at 300 r.p.m. to twin horizontal turbines under 125 ft. head; a six-panel Wagner switchboard, two banks of oil transformers, and two outgoing circuits. All contents thus in duplicate were assembled in two complete, independent units, designed for operation inde-

2. An interesting account of this work and some of the technical results may be found in Mr. Mershon's report, quoted in a paper read by Mr. C. F. Scott before the A. I. E. E. at the Omaha meeting, July, 1898.

pendently, or in parallel, at both high and low pressure. Prior to the power-factor indicator, a device which answered a somewhat similar purpose was installed, consisting of a wattmeter on the low-pressure paralleling bus with current coil in one bus and shunt across the other two. This indicated cross-current, and was used in the adjustment of field charges. Transformers were each of 250 kilowatts, 800 to 40,000 volts, star-connected at both high and low pressure, with neutrals grounded.

Triple-pole air-switches and 4-ft. fuses formerly connected each bank of transformers with its transmission line. One form of air-switch, opening 6 ft., contained no metal except conductors, and was composed entirely of paraffined wood and rawhide, without porcelain, glass, or other insulator. Others were sliding frames carrying line insulators.

During the first year of operation the transmission comprised a single 32-mile line to one receiving point at Mercur, where the arrangement was similar to that at the power-house, save that two reducing transformers were connected two-phase — three-phase, grounded neutral, for 220-volt, two-phase induction motors. The Provo-Eureka line, 42 miles long, carries seven-strand aluminum cable equivalent to No. 4 copper. The Eureka-Mercur cross-line, 28 miles long, equivalent to No. 5 copper, was added to complete the triangle thus formed and permit cutting out either of the three sides without interrupting service.

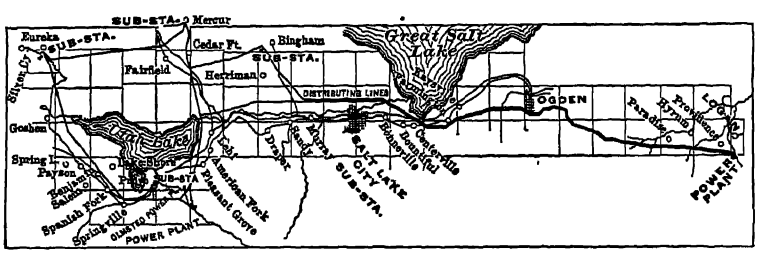


FIG. 5.—MAP OF UTAH VALLEY, SHOWING POWER-HOUSES AND TRANSMISSION AND DISTRIBUTION LINES.

The Logan plant was completed in 1901, containing two 1000-kw, revolving-field alternators, direct connected at 400 revolutions to double-discharge twin turbines under 212 ft. head. This plant is connected with the Provo system by duplicate lines over 100 miles long, passing the cities of Ogden and Salt Lake. The Provo and Logan plants are thus operated in unison through nearly 200

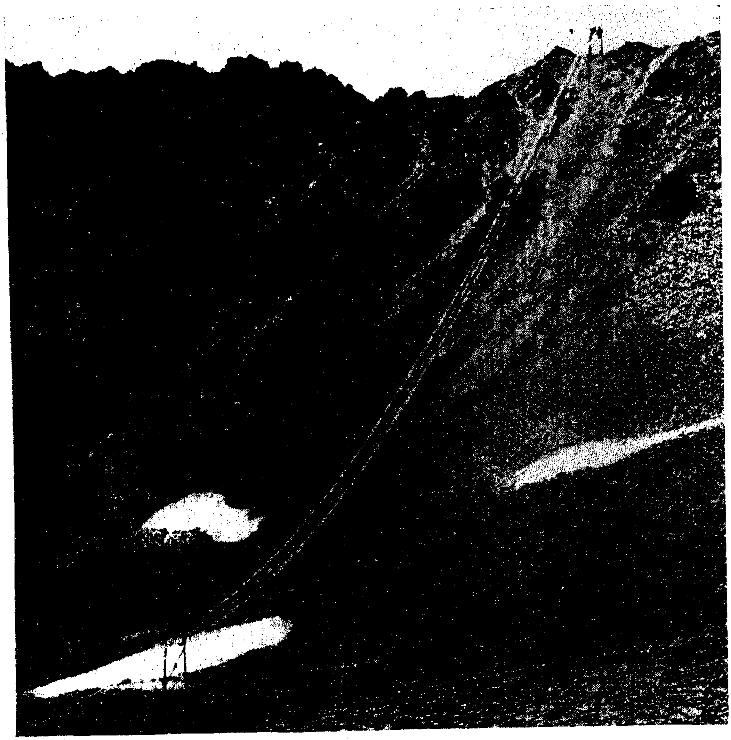


FIG. 4.— LONG SPAN AT CAMP BIRD DIVIDE.

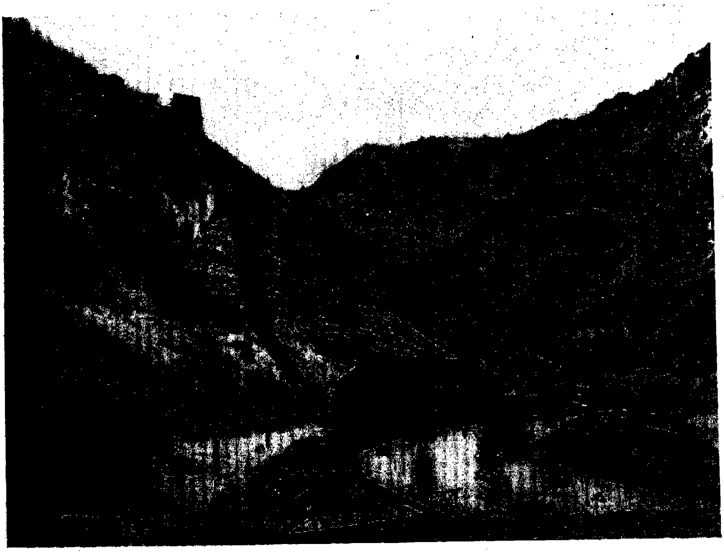


FIG. 6.— THE LOGAN POWER-HOUSE.

miles of transmission. Distributing points at Mercur, Eureka, Bingham, Salt Lake, and Provo are also junction points of the duplicate lines, equipped with switches in each incoming line, as well as in circuit with the transformers, so that in case of threatened trouble the patrolman can, without delay, have his section cut off for immediate repair without interrupting service.

The three conductors of each transmission form an equilateral triangle 76 ins. between wires, carried by a 7-ft. cross-arm and the top of the pole. Extra long pins raise the insulators from 6 to 12 ins. above cross-arms, are of selected locust, kiln-dried and immersed from 6 to 12 hours in hard paraffine at 150 deg. C. Cross-

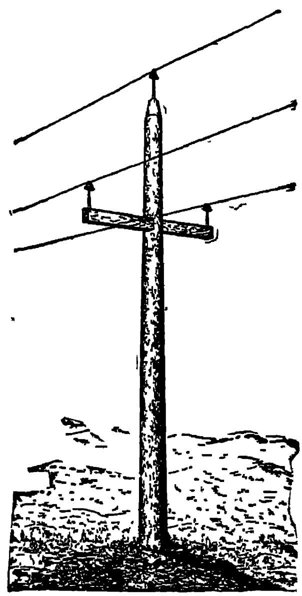


FIG. 7.—PRESENT ALL-WOOD POLE CONSTRUCTION.

arms are of Oregon fir, kiln-dried, and soaked in boiling bitumen. Those upon the first line were attached in the usual manner with metal braces. The burning of cross-arms and poles on account of broken insulators, during prolonged wet weather, occurred most frequently at these braces. When the next lines were built in 1899, treated wooden braces were substituted, with results so favorable that all metal braces were soon replaced. It was still observed, however, that even light leakage seemed to concentrate around the lag bolts, carbonizing the wood and finally loosening the bolts.

For the Logan lines of 1900 and all later lines, therefore, the cross-arms were mortised through the poles and wedged and pinned with hard wood — thus discarding all metal except conductors. This construction was originated by Mr. A. L. Woodhouse, who, upon the close of the high-pressure experimental work in Colorado, of which he had charge, became and still is superintendent of the Utah department. It has proved amply strong, not expensive, and during the four years' operation of the 400 miles thus constructed very few poles have been burned.

Provo-type glass insulators, designed by Mr. V. G. Converse, have been used throughout. Many have broken, but these have usually shown the effects of guns or stones. In fact, there has not been a single breakage, except in one lot improperly annealed, clearly due to either internal or dielectric stresses. It is difficult to see wherein any other insulators could have done better, unless bullet-proof. College laboratory tests to the contrary notwithstanding, leakage losses are inappreciable except during severest storms, and then not serious where insulators are unbroken. It is a mistake to suppose that Utah climate is favorable. During the rainy season it is as wet as any, and the alkali dust of the so-called salt storms is as trying as sea-coast spray. At times dense volumes of this impalpable dust from the Great Desert are accompanied by clouds or fog. In this damp, sticky state the dust completely covers to a considerable depth the under, as well as the upper, surfaces of insulators, as well as poles, cross-arms, and pins. Over these surfaces streamers gradually creep until, meeting at the pole, they break into an arc, like that which was photographed by Mr. C. E. Baker, the line patrolman at Mercur, and which has several times been published. A quick turn of the generator rheostat at the critical instant breaks the arc without interrupting service of induction motors.

The arrangement of power-houses and transmissions already described is such that the opening of paralleling switches may resolve the system into a single transmission from 100 to nearly 400 miles in length with a generator at each end, yet side by side. If one generator be reversed, synchronized as a motor with the other and loaded by its water wheel, any length of transmission may, by manipulation of a paralleling switch, be alternately cut in and out between them. Since switchboards and instruments are connected, measurements made are immediately comparable. In this

manner losses and power factor may be measured, and the corrective effect of charging current observed.

Solid aluminum wire, first used in 1898, was slightly alloyed to increase strength, but proved worthless, breaking repeatedly with square, glass-like fractures. It was at once replaced with commercially pure, seven-strand cable, still in use. Similar cables have generally been employed for subsequent lines, while spans have been successfully increased to 180 and 200 ft., with less deflection than usual with copper.

The experience with oil transformers for 10,000 volts at Telluride, and the refusal of manufacturers to give any guarantees whatever for other transformers for higher pressures, led the Telluride company, when undertaking this 40,000-volt transmission, to manufacture its own. The first equipment was made at the Wagner Company's works under designs and supervision of Mr. Converse. The later ones were made by the Converse Transformer Company. When erected, the oil in the tank and the transformer in an oven were slowly raised to, and then maintained during 24 hours at, a temperature of 125 deg. C. The transformer was then immersed in the oil, and both continued at the same temperature for a further 24 hours.

As bearing upon the question of fire risk due to oil transformers, it may be of interest to note that of the large number of these high-pressure transformers used during the past seven years, chiefly in isolated sub-stations containing much wood and seldom visited, all but four are still in operation; that these four were destroyed by fire of doubtful origin, and that only one transformer has required repair other than change of oil.

The plant at Norris, Mont., designed and constructed in 1901, by Mr. O. B. Suhr, Superintendent (now resident engineer of the Ontario Power Company), contains at present two low-speed 1000-kw units. A duplicate transmission of 60 miles conveys power to the city of Butte. These lines, as well as both raising and reducing transformers, were designed for the use of 40,000, 60,000, or 80,000 volts. Longer pins are used than in Utah, and conductors form a triangle of 108 ins. While producing the present limited amount of power, and awaiting a suitable insulator, the lower voltage has been used.

In conclusion, it may be said that the Provo plant — the first transmission at more than 16,000 volts — while undertaken materially in advance of the art, and not exempt from its share

of troubles, has, nevertheless, been fully successful as a financial venture, and not without value in the progress of the science. Long periods of perfect operation, monotonous in their uneventfulness, have proven beyond question the success of high pressures for long distances. The new and larger power-house at Olmsted, at the mouth of Provo Canyon, completed this season, is modern in every detail. It contains three 3600-hp generators, operating under 340-ft. head. Air-switches and fuses are everywhere giving place to oil-switches with time-limit automatics, and constant reconstruction to meet its increasing demands keeps the system as a whole abreast of present practice. Thus The Telluride Power Company, while again and again a pioneer in power transmission, must not be associated alone with the experimental methods of early days, but may, in the future, be found still engaged in progressive, practical, pioneer work.

Discussion.

Mr Bunker: There is one point I would like to ask, if I may, and that is, how large a wire could be used, for mechanical reasons entirely, on that entirely wooden construction?

Mr. Nunn: The construction used in Utah is considered safe for wires up to No. 3-0 or 4-0. That in Montana, designed for 80,000 volts, employs pins too long for such large sizes. By adapting the dimensions and design of both pins and cross-arms, it may be possible to make all-wood construction suitable for any size of conductors. It would not be difficult to show that the paraffine permeates the pins. A 4″ x 4″ piece of oak several feet long has been permeated, as shown by chemical tests upon a sliver taken from its center. This cannot be done by the usual method of boiling in paraffine, but while requiring care and exactness, has been accomplished by the method previously described. The 40,000-volt circuits from the Provo power house pass through the wall in bushings consisting merely of double flexite tube within paraffined oak tubes 5 feet long, having 1-1/2-inch walls. The bushings are fully exposed and during storms are always dripping, yet have never given trouble. The all-wood switch mentioned has four feet of paraffined oak between 40,000-volt wires.

Mr. Humphrey: I would like to ask whether the poles have ever been treated — that is, the top of the pole? Pins have been treated, cross-arms have been treated, and it seems to me to be practical to treat the upper ten feet of the pole, rather than to abandon the wooden construction and go in the steel-pole construction altogether. I would like to ask if that has ever been tried?

Mr. Nunn: No attempt has been made to paraffine poles, but they have been treated to some extent with hot bitumen, especially at their tops and upper pin holes.

CHAIRMAN SCOTT: Three weeks ago to-day I spent a most profitable and pleasant day in the Provo power house at Olmstead, which Mr. Nunn has described to us. Mr. Nunn has introduced a new method of high-tension wiring, by running the high-tension wires through fibre tubes. This makes a remarkably neat and compact construction for the high-voltage work. The whole power house and its surroundings are laid out in a very excellent way. There is at this plant excellent provision for the young men who are in attendance at the power house.

MR. NUNN: In the early days, when every synchronous motor required two or three attendants for its 24-hour service, it became necessary to provide opportunity for non-technical but bright young men to learn enough about the apparatus and sufficient of the subject generally to fit them for these positions. The training begun at that time has never altogether passed, and there has ever since been something in the way of a student course. In connection with the new plant at Olmsted, special provision has been made in the way of quarters, lecture rooms, laboratories and a gymnasium for extending this feature and for giving it a permanent character and home. The purpose is to conduct post-graduate research side by side with practical design, construction and operation of engineering works, whereby young men may undergo that critical transition from the receptive college student to the executive, practical engineer of affairs.

CHAIRMAN SCOTT: There is another side of this power transmission work, and of electrical engineering work in general, which has not come into our discussions until introduced by Mr. Nunn just now. It is the human side. All the power transmission systems that we have now, transmitting, at what might be termed high voltages (10,000 volts or over), something like a million-and-a-quarter of horse-power, in which we had no experience ten years ago, have made an evolution not only in pins and insulators but also in men. The men have had to be developed; they have had to go from one kind of work to assume responsibilities in larger work, with more exacting and unknown conditions, and if the curve of electrical activity is going to keep on increasing, more men for the work we are doing now, and more men for undertaking these new problems must be developed. The colleges are doing much. I have met during this week a host of young, enthusiastic, energetic college professors who are here in touch with the work of this Congress and of the exposition, and who are going back to keep on grinding out young electrical engineers. Those young men were not appearing fifteen years ago; the colleges were not then making them; the college did not have the facilities. Now it is turning them out in great numbers. Manufacturing companies are taking them, operating companies are taking them, not only in power work, but telephone and other companies, and I believe the important thing now, the big evolution, in a way, in electrical work, is the development of young men who are going to be a big factor in this work in the next ten years. In the company with which I am connected men are received and given a training for a couple of years, such as that of which Mr. Nunn speaks, and I was surprised a few days ago to see in a list of the men who have been received within the last three or four months that practically fifty institutions are represented by from one to

half-a-dozen men. Now, not quite so large quantitatively, perhaps, but in the same general line qualitatively, Mr. Nunn is going to take young men and give them opportunities for running a station and learning the operation of a power transmission system; and the elegance of his station and of the cottages and facilities which he is building up at Provo mean that the young men are going to be well taken care of in other ways besides electrically.

Mr. Peck then read the paper by Mr. L. M. Hancock, entitled "The Bay Counties Power Company's Transmission System."

THE BAY COUNTIES POWER COMPANY'S TRANSMISSION SYSTEM.

BY L. M. HANCOCK.

In treating of this subject it is taken for granted that the majority are familiar with the details of the Bay Counties Power Company's system which now forms a less important part of the plant of the California Gas and Electric Corporation.

Only an outline of the general and controlling features will be given, dealing more at length with the organization of the forces to operate the plant and to carry on construction and repairs.

Considering organization, the plant falls into the following three natural divisions:—

1. Generating.
2. Transmitting.
3. Distributing.

The first comprises all water systems and power houses. The second, all high potential transmission lines and their fixtures. The third, all substations and low potential lines and their fixtures.

The main features of the plant and the attention they require are as follows:

Diverting Dam. Log crib, rock filled, 40 feet high and about 200 feet long on the crest. The intake and headgates were of concrete and very massive and ruggedly substantial throughout. The dam needed and could get attention only during periods of low water; then it was examined thoroughly each year and whatever repairs were necessary were made preparatory to another season's submergence which lasted the greater part of the year. The gates and intake needed some attention which was all given by the flume men.

Main Flume. Seven feet wide, six feet deep, seven and one-half miles long, through one of the most rugged pieces of canyon in the State. This was the most difficult part of the system to construct on account of inaccessibility. It was also one of the most difficult parts of the system to keep up to a high standard of repair, and on

account of local conditions must be very carefully watched to avoid danger and to care for the numerous accidents as they arose. It must all be inspected each day to take care of many little things that needed prompt and immediate attention though the main repair work was attended to once a year.

The Main Penstock at the end of this great flume was built of concrete and besides receiving water from the main flume was arranged to be fed in an emergency with water from Lake Francis, through 9000 feet of 36-inch wooden stave pipe, 1/2 mile of natural channel and 3000 feet of rapid flume. This penstock delivers water to Colgate and to the old Brown's Valley irrigation system. On account of previous troubles with the pipe lines, variations in the flow of water, and the great dependence put on this plant, watchmen were stationed at the penstock and held there constantly.

The Five Thirty-Inch Pipes carry the water from the penstock and deliver it into the receivers back of the power house. These pipes were very carefully installed and need only an occasional inspection, which is given by the power house superintendent or foreman after severe storms early in the spring and late in the fall.

Being covered for the greater part of the way, this inspection of course only takes in exposed portions and surface indications, leaks, conditions of retaining walls, breakwaters, etc.

Water is distributed from the receivers to the 16 water wheels through small pipes and suitable gates. All the small pipes, connections, gates, etc., near the power house get regular attention from the forces employed there. Inspections are frequent and every item has continual care.

The power house equipment is as follows:—

Generators.

3	2000-kw,	240 r.p.m.,	3-phase,	60-cycle,	2400-volt,	inductor.
3	900-kw,	360 r.p.m.,	3-phase,	60-cycle,	2400-volt,	inductor.
1	720-kw,	286 r.p.m.,	2-phase,	133-cycle,	2400-volt,	inductor.
2	50-kw,	800 r.p.m.,	exciters.			

Suitable tangential water wheels with deflecting nozzles are directly connected to each generator and exciter. The low-potential switching is made as simple as possible and only such instruments are centralized as are needed to control the plant. The balance are scattered about the building near the apparatus to which they belong. Oil switches are used exclusively for the 2400-volt circuits,

at which voltage all the machines operate. *The Transformers* are all oil-insulated and water cooled, the majority of them are 750 kw, but there are a number of smaller sizes. They all require almost no care and being in the power house have constant attention.

All low-potential wires and cables are run in a subway, while all the high potential wires and connections are overhead in the gallery. Originally an immense amount of wood was used in mounting the high-potential switches, lightning arresters, etc.

This construction was all destroyed in a fire, March, 1903, and has been replaced by a brick and tile and steel construction built up on the cellular system.

The unique feature of Colgate is the number and variety of very high potential circuits radiating from the plant. The following table gives a list of them:—

Name of circuit.	No. of circuits.	Length in miles.	No. of pole lines.	Material.	Phase.	No. wires in each circuit.	Cycles.	Kilovolts.
Bay	2	140	2	$\frac{3}{4}$ Copper ...... $\frac{1}{4}$ Aluminum ..	3	3	60	40-50-60
Sacramento	2	61	1	60 M: Alum..... 1 *m* Copper...	3	3	60	40
Oroville	1	28	1	Aluminum	3	3	60	40-50-60
Marysville ...	1	28	1	Part { Alum.... Copper..	2	4	60	15
Nevada	1	19	1	Copper	3	3	60	24 } On same pole line
Nevada	1	16	1	Copper.........	2	4	133	24

This variety of service can only be handled successfully at the power house end by either using individual transformers for each line, by using a great many high-potential switches, or a combination of the two methods. The first, however, makes it necessary to have a great deal more transformer capacity than is necessary for the loads handled. The second method was pioneering to an alarming extent. Therefore the third method was adopted planning to use as few of both devices as possible. The odd phase and voltage lines had to have separate transformers which were operated from the low potential switches and were to all intents and purposes a part of their respective lines. The growth of the plant was such that the odd voltage three-phase lines could not be avoided; however it was planned ultimately to have these all operated at the same tension.

The question of high-potential switching was one of very great moment and must be solved, yet it is not to be trifled with.

There were four designs of switches employed, as follows:

First, an emergency switch, which when open or closed was perfectly safe but would not stand being opened under full voltage and heavy current. This was simply a blade about thirty inches long with jaws mounted on large insulators which were carried and held in place by suitable frame work, the blades being pivoted to one of the jaws. These switches were suitable for cutting out a dead line or would open the full voltage of a thirty mile line if there were no load on it. They were also adapted for cutting in and out banks of unloaded transformers but with full voltage on. They were used in series with main switches, lightning arresters and other devices that must be taken out of service occasionally without having to shut down, and were also employed for temporary work and testing.

Second, the Stanley switch, which was arranged to break the arc in a tube filled with plaster paris. This served the purpose in the absence of anything better, but was clumsy, slow of operation and often out of repair.

Third, the oil switch with horizontal break. This switch was not installed where it had to handle heavy loads, but there were some very severe tests put on it which it stood remarkably well. These tests consisted of opening a dead short at a distance of 100 miles from Colgate with full generator capacity behind the line.

Fourth, the oil and water switch. This switch in its original form was put under extremely severe tests which it stood wonderfully well, opening 25 dead shorts on a 40 K.V. line in quick succession, some of which were 240 miles from the generator via the pole line. However the design of this switch was not suitable to the duties required of it. During a severe lightning storm it broke down and was not replaced. The consensus of results pointed to the horizontal break oil switch as the one that stood the test of actual service the best of any.

The Substations and the wiring for them were as various as could be imagined. The transformers as a general thing were wound so that they could be used anywhere on the system, and taps were brought out so that either three-phase or two-phase circuits could be fed from them. Three transformers were generally used and taps were brought out from the winding so that the voltage

could be varied as needed. When two-phase service was given from three transformers, it was found unsatisfactory for motor work on account of the regulating coils varying the phase angle. In several cases a single transformer was installed for single-phase service in small towns, the high-potential side having one wire attached to one of the line wires and the other to a ground plate, very satisfactory service being given in this way in small towns.

The substation buildings varied from steel frames covered with corrugated iron in important locations, to an ordinary wooden building in some of the small towns.

The Switchboards in a few of the larger stations were quite complete, but in the majority were very simple, there being generally apparatus to meet only the most urgent needs. High-potential switches were usually provided in each station; in the larger ones they were either Stanley or horizontal oil break; in the smaller stations, the cheapest kind of a long knife switch. Devices were usually provided outside to cut the line clear from the building. Ten substations were put into service when the line went into commission. In three years this number had increased to twenty-six. The majority of these stations needed little attention.

The organization of the forces to operate this system was a most difficult task. There was no experienced class to draw from so men had to be educated for the work, and meanwhile the system had to be kept going. There must be more men than was actually necessary, yet in the trying out of so much new apparatus there was no telling how many men would be needed for emergency work. There must be no delays in repairing breaks for financial men the country over were watching the results and a little parsimony might mean thousands of dollars lost in depreciated securities.

The water system consisted of the following items in the order of their importance:

First: Main section, dam, flume, and penstock.

Second: Auxiliary section, Lake Francis system.

Third: The middle section from Colgate penstock to the Brown's Valley power house.

Fourth: The lower section below the Brown's Valley power house.

The Lake Francis auxiliary system is placed second in order of importance, though as it exists it is not worthy of the place for it is so far removed and the conduits are so small that it does little

good as an auxiliary. The writer urged very strongly when the original plans were made that they provide a penstock reservoir of sufficient size to operate the plant for a few hours at least. Had this been done the operating expenses of the hydraulic system could have been kept at less than one-half of what was found to be necessary. In other words, an average of ten men are now needed if the system is kept up to the proper standard, while with the reservoir only four would be needed; a saving of $5,400 per year which capitalized at 5% equals $108,000.

This sum, plus the actual cost of the Lake Francis system would have been amply sufficient to put in the reservoir suggested.

This is an excellent illustration of how the design may affect the future operating expenses.

The conditions facing us were these: The system as installed must be utilized to its fullest extent and at the least cost. With this understanding the following organization was adopted:

Superintendent — Foreman:
- Main Section:
  - 6 Flumemen.
  - 2 Penstock watchmen.
- Auxiliary Section:
  - Permanent watchman at lake.
  - One winter watchman at end of wooden stave pipe.
- Middle Section:
  - 4 Ditchmen.
- Lower Section:
  - 1 Ditchman.

This force handled all the work well except the yearly repair work and cases of extreme emergency. Then extra men were brought in from other parts of the system or from outside sources.

While the flume was new there was no great trouble in making the natural repairs, but as it grew older, timbers began to rot, twist, and crack and repairs of magnitude had to be made. Many places were patched up and from the very nature of things had to be left till an opportunity came for thorough work. As long as the planking that actually held the water remained intact the balance of the repairs could be made with extra care and expense, but when a rock would come rolling down the hill and knock out the under-

pinning or smash a hole through the flume itself, it was simply a case of shut down till damaged parts could be replaced.

This shutting down of 10,000 horse power, even for a few hours, was no idle matter and a thing every one dreaded.

The superintendent of the water system held an anomalous position; while taking his orders from the general superintendent direct, he must at the same time take orders from the Colgate superintendent in regard to the water furnished for the power house.

He must get over the whole of his system at least every month and must be on hand to take care of any emergency that might arise on the main flume, and there were many places on this important section that had to be watched continually in order to meet difficulties half way.

The foreman devoted all of his spare time on the main section, supervising repairs, looking after the placing of new material, maintaining discipline and ever holding himself in readiness for emergencies. The six flume men did little but patrol the flume; minor details they took care of however and always helped in cases of an accident. Two men were kept on watch at the penstock all the time.

These could do but very little except to stop any leak that might occur in the neighborhood, keep rubbish off the rack at the entrance to the penstock and attend to the adjustment of the various gates in the neighborhood. If there were a break in the flume, one or both were expected to assist in its repair. There was an elaborate system of floats and electric bells installed for detecting low water at various points a mile or more above the penstock but these devices were seldom of any value except to talk about.

When anything happened of a serious nature, the water always slacked away so quickly that everything, flume, penstock and all was emptied before the water wheel nozzles could be closed.

There were 14 gates to close these nozzles, each gate requiring ten minutes to operate it; hence with only three men on shift to do this it was quite a simple matter to predict what would happen.

On the middle section four ditchmen were employed who did practically all the repair work on their beats besides making their tour of inspection each day. This part of the system consisted of 20 miles of ditch and flume. It carried only 1,200 inches of water and was an old settled piece of work.

The lower section of the water system consisted of 22 miles of

ditch and a few short flumes and inverted syphons and as it furnished only some irrigation water and some little desultory mining, it was of so slight importance that one man handled it successfully. Each year a force of from ten to twenty men were put on for a few weeks doing general repair work. At this time every feature of the system got an overhauling and whatever repairing it needed. Thus the whole system was put in readiness for another year of hard service.

The handling of this water system while very exacting, involved nothing new or strange. Materials such as men were familiar with were used and the handling of flumes was no new work for Californians with but this one exception; for power purposes without any storage, the full head must be kept running all the time, while the ordinary service to which flumes are applied water can be turned out at any moment it may be desired without causing any serious trouble.

The water system was peculiar in that none of the men ever saw any of the customers of the company and in fact seldom saw any but their immediate fellow workmen. Their cabins were in very isolated places and they seldom met any of the officers of the company. Theirs was a monotonous life with but little to inspire them. Their business was to deliver water and as long as that was done no one complained nor did they praise.

The Colgate power house was the center of the whole system and the whole aim of the operators was to put out energy.

This was dependent, (a) on the water system delivering water to them; (b) on their ability to utilize it and to keep in working order the apparatus in their care; (c) on the line department keeping the lines in order, to transmit what they generated; and (d) somewhat, on the distribution system being able to receive and deliver to the customers what the line department handed over to them.

After the power house force had kept its apparatus in repair and in operation, they must, in order to succeed, be in harmony and in close touch with all the other parts of the plant. Hence the emphasis on a complete and efficient system of communication. This was not so evident on the water system, for immense systems of flumes and ditches have been and are operated without any means of communication other than messenger or mails.

Items (a), (b) and (d) did not interest the power house force; they must concentrate on their own troubles.

The principal item on which success depended here was the repairs of damaged or worn-out apparatus, so in order to facilitate this a large supply of new material and spare parts were kept on hand and a large and well equipped machine shop was installed and men were appointed on the force that could utilize these tools to their full value.

The forces here, though dependent so much on the others for success, were never allowed to get the idea of covering their own mistakes by attracting attention to the troubles of others. The handling of this power house had only these three features that distinguished it from all other large power houses.

First. It must feed numerous high voltage lines of various voltages, phases, cycles and lengths.

Second. It must run in parallel with other large plants that were many miles distant and operated at different voltage and phase.

Third. Its service reached almost every known business where power can be utilized, and there was not a moment in the year when a great many were not exceedingly anxious for energy.

While this was the case, the only feature of uncertainty at the start was that of the high-potential lines, switches, lighting arresters, etc., but after a year's experience it was found that to this apparatus could be charged no more than a proportionate share of the troubles.

It was decided that for Colgate there should be the following organization:

Superintendent ranking as a division superintendent:
- Foreman:
  - Assistant Foreman:
    - 3 Shift bosses.
    - 3 Operators.
    - 3 Oilers.
    - Machinist.
    - Apprentice to Machinist.
  - 2 Telephone Operators.
  - Repairmen as needed.

The superintendent, while not having absolute authority over the flume superintendent, in the one question of water supply his word was final. Besides this he was a man of much wider knowledge and experience which was all of very great value to the company

and of which they wished the benefit. It was ordered that each should draw on the other in case of need and they must be in perfect harmony with each other. Besides having charge of Colgate, this superintendent had charge of a small power house of 1,000-horse power situated about nine miles distant and known as the Brown's Valley plant. On account of this, the Colgate and the water system superintendents were brought into still closer contact. The Colgate foreman had charge of all the day work, operating. repairs, new work, etc., and ranked next to the superintendent. The assistant foreman had charge of all the night work and ranked next to the foreman. The shift bosses were under the foreman and assistant foreman and had charge of the operation of the power house during their shifts.

They were directly responsible for everything that happened and the condition of the apparatus. They must see that everything was all right when they took charge and anything wrong when they came on duty must be reported at once else they would be held responsible. They were also responsible for the two men under them. Each shift was 8 hours and the operators were changed one shift ahead each two weeks. The machinist and his apprentice were free lances that had to do whatever was to be done at whatever time it was necessary. They did the greater part of repairing and improving of machinery.

The lines which have always been the "weak sister" demanded and got especial care and attention. It might be said on general principles that there never is enough money put into the lines.

We will deal alone with the 140-mile line, because this is typical of how all the others were handled, especially those carrying the higher potentials. The greatest care was taken in handling them, for they were unusually long and every move was watched with the keenest interest. Failures would receive the severest censure, because reaching to the very doors of San Francisco the service we were giving would be before the public in a much more important and effective way than anything we had yet handled. If the street cars of Oakland, which were the principal load at the start, did not run, the men who handled them and the public too were not slow to blame the trouble on the source of power. Hence every detail was studied and every plan possible carried out to get complete reports of the condition of the line every few hours of the day. Elaborate precautions were taken to discover any weakness

and repair it before a break down could result. However, we could not always tell just how fast things were going to happen. There were three items that required attention:

First: The watching of the line and searching for weak places as they developed.

Second: The completion of the work which the construction forces had not the time to finish and the building of new branch lines.

Third: The repairing and changing of parts that were found to be faulty or unsuited to the conditions.

To attend to these the following plan of organization was adopted:

Line Superintendent ranking as division superintendent:
- Assistant Superintendent:
  - Patrolmen.
  - Foreman repair gang:
    - Linemen.
    - Laborers.
  - Bookkeeper.
- Telephone Expert.
- Superintendent of new Construction:
  - Engineers.
  - Surveyors.
    - Rodmen.
    - Chainmen.
    - Axmen.
    - Laborers.
  - Foreman Construction Gang:
    - Linemen.
    - Teamsters.
    - Laborers, etc.
  - Freight Distributing Agent.

The superintendent of lines for the first year spent nearly all his time getting back and forth along the line, studying conditions as developments came, instructing the men, and keeping them up to their work. The importance of this work made great demands on the time of the general superintendent.

The assistant line superintendent devoted a good deal of his attention to the office work, checking reports, ordering and forward-

ing material, looking after the repair work, and working between trips with the line superintendent.

The telephone expert was in a position that he had to work under nearly all the superintendents though he was nominally under the line superintendent. His was a study in harmony. His work extended from one end of the plant to the other and as the name indicates devoted the greater part of his time to the solving of difficulties, designing and installing protective devices and working the telephone system so the highest efficiency could be obtained. He was always supplied with material and men on call. If communication could not be maintained, the plant could not be operated.

The superintendent of construction was utilized almost exclusively on new work, and hence had little to do with the operation of any of the lines, except when they first went into commission. He was expected to use every opportunity to study developments in order to assist in any way possible to the general success.

In order to care for the line thoroughly, patrolmen enough were put on so that they had an average of 14 miles to cover each day. In the mountains and marshes the beats were shorter and in the valleys longer.

The whole line must be put into shape so every part of it could be reached. In the hills trails must be dug, creeks bridged and barns built for horses. In the marshes and flooded lands boats must be provided, everywhere gates must be put in fences and above all certain communication must be provided.

The work required that the patrolmen should not do very much of the actual labor connected with the upkeep of the line. They carried a number of tools and a portable telephone and were always called on in emergencies. They must report on duty in the morning, get over their beat at a slow enough gait to be sure of the condition of every detail, report several times during the day and report off duty at night. Usually by the time they had attended to all the above, they had accomplished a very good day's work. Most of these men used saddle horses; in fact there were only one or two beats where a wheeled vehicle could be used to advantage. Material was stored at various places along the line so that it could be reached conveniently in case of trouble. The work of patrolling was so new that there was no class of trained men to draw from so each patrolman had to be educated. In fact the officers in charge had to make an unusually close study of it, living with it almost

night and day for two years. A host of questions were asked and few of them answered before the line went into service. As the answers came they must be recognized quickly and the work pushed accordingly.

It looks a little strange to put on a repair gang almost before an installation has gone into actual service. This was on account of the work being so new that there was no experience to guide those who designed the various parts of the equipment.

Some of the questions to which we had to learn the answers in the field, were:

To what extent will the wooden supports of the line be destroyed by the high potential used?

How will the insulators, which were a composite glass and porcelain, stand the actual strain of operative conditions?

How much of the insulator can be broken off before it must be removed from the line?

How much dirt can accumulate on an insulator before it must be cleaned?

How noisy can an insulator get before it is dangerous?

What effect will fogs produce?

What effect will rain produce?

If a line gets shut down in a rain storm, can it be started up again and with what difficulty?

How will long spans stand up?

What will be the result of using steel for line supports?

As the work progressed answers came to all of these about as follows:

Wood pins were destroyed by the hundreds near salt water; cross-arms a few, and poles only two or three in the course of three years' service.

Glass is not suitable for high-potential insulators under the conditions as they exist on this system. An all-porcelain insulator has been and is being substituted for the composite insulator as fast as conditions will permit, especially near salt water.

The insulator first installed had so little margin of safety that if it were broken at all it was ordered removed from the line.

If only a small piece were chipped out of the edge the risk was taken for a time.

The only place where we had trouble with the accumulation of dirt on insulators was near salt water and cement works.

There may be a good deal of noise at an insulator on a wood pin for many weeks and not much damage result, but it should be watched closely. With a steel pin and a wood cross-arm this noise will not be anything serious except in some unlooked-for place, due to local conditions. These should be watched closely on general principles.

Ocean fogs cause the burning of very many wood pins, while cross-arms and poles suffer but little.

Fogs a few miles back from salt water do not affect either pins, cross-arms or poles.

Rain is Heaven's own blessing on a high-potential transmission line. It cleans the insulators and stops a good deal of the damage to wooden supports. This is true of salt water districts especially. The first few drops that fall after a prolonged dry spell causes a good deal of a display which soon passes however and all is quieter and better than it was before. This display does not affect the power house load to an appreciable extent nor does it affect lights or motors.

The starting of this line in a rain storm never caused the slightest trouble, in fact in changing from one line to the other full voltage has many times been thrown instantly on the dead line during heavy rain storms without the slightest disturbance that any one could detect.

The experience has been that long spans are preferable in almost every case. On a mountain line built about two years ago some very long spans were used. One was 1,800 feet with the regular line conductor, a 350,000 cm stranded aluminum cable, and it has given the best of satisfaction.

Every indication is that steel should be used for high-potential line supports from the ground up to the insulator throughout the system.

The substations and distribution work were handled almost entirely by the local men, nearly all of whom were under a separate management. A superintendent of this work was maintained whose duties were mainly to advise the local men in regard to the handling of the company's property and to see that it had proper care.

At the majority of the substations a man would be on duty only for a time during the evening when the lighting load was on, unless there was important high-potential switching to be done.

The low-potential distributing systems gave very little trouble

and it was very seldom that they were not able to utilize the current available.

The men for all the positions were very carefully selected from the whole country. The repair and construction forces were used as training schools for men for permanent positions and the foremen of these gangs were selected with this specially in view. These forces were used too as places to lose out undesirable characters.

The following ideas were advanced to guide in the handling of the men:

First. Harmony must be maintained.

Second. There must be a definite sequence of authority to prevent working at cross purposes.

Third. Each man must respect and obey the officer immediately over him.

Fourth. Each man had the assurance that his advancement depended on himself alone; that all the higher positions of the operating, repair and construction forces were open to the men handling the plant if they would fit themselves for them.

Fifth. The longer the time of service the better the pay.

Sixth. A sufficient number of men must always be kept to insure excellent service, but there must never be so many that each man's time will not be fully occupied.

The officers and the sequence of their authority for the whole system were as follows:

- General Superintendent:
  - Water System Superintendent:
    - Foreman.
      - Flumemen.
      - Repairmen.
      - Emergencymen.
    - Auxiliary Section:
      - Lake watchman.
      - Winter watchman on wood stave pipe.
    - Middle Section:
      - 4 ditchmen.
    - Lower Section:
      - 1 ditchman.

Colgate Superintendent:
- Foreman:
  - Assistant Foreman:
    - 3 Shift bosses.
    - 3 Operators.
    - 3 Oilers.
    - Machinist.
    - Apprentice to Machinist.
  - 2 Telephone operators.
  - Repairmen, etc.

Superintendent of Lines:
- Assistant Superintendent:
  - Patrolmen.
  - Foreman repair gang:
    - Linemen.
    - Laborers, etc.
- Superintendent Construction:
  - Engineers.
  - Surveyors.
    - Chainmen.
    - Rodmen.
    - Axmen.
  - Foreman:
    - Linemen.
    - Teamsters.
    - Laborers, etc.
  - Time-keeper.
  - Freight agent.

Superintendent Substations.
- Substation operators.
- Local managers of business districts.

Chairman Scott then read the paper contributed by Mr. R. F. Hayward, entitled "Some Practical Experiences in the Operation of Many Power Plants in Parallel."

SOME PRACTICAL EXPERIENCES IN THE OPERATION OF MANY POWER PLANTS IN PARALLEL.

BY R. F. HAYWARD.

Local conditions and force of circumstances have developed in the United States and Canada several large power systems, consisting of a number of long-distance transmission plants operating in parallel, and supplying power for all conceivable purposes over wide areas of territory. The growth of these systems has covered a period of nearly 10 years, and the time is opportune to review the lessons learnt in their upbuilding. The mistakes, technical and financial, which were necessarily made in the pioneering of long-distance transmission of power have been turned to profit, and plans are now being followed out along comprehensive lines, to meet the demands of a market which has grown more rapidly than ever was pictured in the dreams of the early promoters.

Three large systems of this kind have grown up in California under the control of the Los Angeles Edison Electric Company, the Standard Electric, and California Gas & Electric Companies; the State of Utah is almost covered by the lines of the Utah Light & Railway Company and the Telluride Power Company; in Canada the Montreal Light, Heat & Power Company is operating a large parallel system; and in the State of New York the Hudson River Power Company is making great developments in this line.

The technical journals are full of articles describing and illustrating these plants and the physical difficulties encountered in building them, but very little has been written about their operation. A description of the difficulties and troubles encountered and overcome in the course of eight years' operation of the transmission plants in the West would, in the hands of a skillful writer, form a most instructive and exciting story. It would be a tale of fights with the forces of nature in the great valleys and mountains of the West; fights against ice, snowslides, floods and rockfalls, brush-fires, windstorms and lightning, where time was always on

the side of the enemy. It would be a record of simple devotion to duty in the difficult and dangerous situations on the part of all the operators.

In Utah, where the author's lessons in transmission have been learnt, the first water-power plant was started in June, 1896, and from the very first was operated in parallel with the steam plant in Salt Lake City. Other plants were constructed immediately after, and by consolidation and reorganization were joined together into one system. The Pioneer Power Plant at Ogden was run in parallel with the Big Cottonwood Plant, 50 miles away, for the first time in March, 1898. Since then there has been a continuous growth of the business, until the beginning of 1904 found the two systems of the Utah Light & Railway Company and the Telluride Power Company running in parallel, covering a district 160 miles long from north to south and including six water-power plants, two steam plants, 420 miles of high-tension transmission line, and nearly 500 miles of circuit. The maximum demand on the two systems was about 10,000 kilowatts, and the load consisted of lighting, street railway, and power for all kinds of service, including flour mills, cement works, brickyards, smelters, air-compressors, cyanide mills and other mining enterprises.

A complete discussion of all the features of parallel operation would involve the consideration of almost every phase of power transmission. Certain points, however, stand out in importance above all others, and they will be discussed in the following order, viz.:

1. The organization of the operating staff.
2. The means of communication.
3. Load factor, and the economical distribution of load between steam and water-power stations.
4. Speed regulation.
5. Voltage regulation and power factor.
6. Arrangement of high-tension lines, switches, and transformer stations, etc.
7. Sudden disturbances on high-tension lines, from lightning, etc.

The statements made in this paper do not, of course, necessarily apply to systems operating under different conditions to those here referred to.

1. The Organization of the Operating Staff.

The success of a transmission company depends more upon the organization and efficiency of its operating staff than on anything else. From the lowest to the highest there should be an ambition to rise to higher responsibilities and a readiness to do anything possible, even to the extent of taking some personal risk, in order to keep the service going through storm and accident. The staff will be composed of technical engineers and artisans. The technical men should have an all-round engineering foundation, and must be especially trained in the art of observation — mere electricians are useless in a large power plant. The artisans should be encouraged to study with correspondence schools as much as possible. Even a helper or stoker who does not endeavor to prepare himself for a higher position should be dropped out. In the operation of many power plants in parallel, more than in any other business, is it necessary that there be perfect harmony between all departments and confidence between operators and their superiors.

The chief operating engineer should have jurisdiction over all power-houses, transmission lines and distributing stations, and should be held responsible for the delivery of the power to the service mains. His headquarters should be at the receiving end of the system, from which points he or his assistants should direct all operations. All operating engineers should be technical men who know every corner of the system. The superintendents of power stations should be held responsible for all that pertains to their stations, whether water power or steam plants, and should be trained artisans, rather than technical engineers.

All the transmission lines operated by one company should be under the care of one man who should have under him a capable staff of patrolmen. It does not pay to use any but skilled linemen for this work, and character is as important as skill.

2. The Means of Communication.

It is impracticable to operate many power plants in parallel without private telephone service between all power-houses and substations. The whole telephone system should be laid out and operated with as much care as the transmission lines. Every important station should have two lines of communication, for when an accident occurs, a power-house may be inoperative until communication is established. It is good practice to build independent

telephone lines parallel to the transmission lines, but this is by no means necessary, as perfect service can be obtained with telephone lines properly arranged on the same poles, either with or without a grounded neutral on transmission line, and the indications on a telephone are invaluable in giving warning of impending troubles, in locating break-downs and in indicating high-volt surges. The requirements for good telephone services are: good insulation, both on transmission lines and telephones; strong construction, so that no storm will break the wires; good protection to operators against accidental high voltage; and transpositions on both high-tension and telephone lines. Without sufficient insulation on the transmission lines for the voltage carried, a telephone line on the same poles is simply inoperative. For the telephone line itself the best of insulation can be obtained by using porcelain insulators designed for 2000 volts lighting service and it pays to do this. All wiring inside and outside of buildings should stand a puncture test of 2000 volts. All plugs and jacks should be replaced by knife switches. Knife switches should be arranged so that both bell and telephone can be cut off from the line. The telephone should be connected on only when in use. For protection of telephones and operators in case of cross with high-tension lines, a simple spark-gap to ground between two large metal cylinders has been found quite effective. These should be placed in a fireproof cell or outside the building. Strength is best obtained by using porcelain insulators and No. 8 iron wire. No copper wire of less size than No. 6 B. & S. will stand the stress of weather without breaking, and iron works very well.

Good service can be procured by placing telephone wires close together and transposing once in half a mile. With high-tension lines untransposed there is considerable induction between telephone line and ground. On a 45-mile 28,000-volt line in Utah, the voltage between telephone line and ground from this cause is about 1000, but in spite of this the telephone service is perfect even in wet weather. Of course any one ground on the telephone line renders the line inoperative, but the transposing of the high-tension line will probably remove this difficulty.

3. Load Factor.

The economical distribution of load on a number of plants operating in parallel is dependent on the load factor of the system. For any given set of conditions, covering cost of construction of

water power and price of steam coal, there is a certain load factor at which it costs the same to generate by steam as water power. If the load factor is less than this amount it pays best to generate by steam, if greater by water. To obtain the greatest returns from a water-power plant every cubic foot of water available must be utilized economically. On a stream where no storage is possible this means a constant load. If there is sufficient storage to take care of daily fluctuations, a water-power plant may be run economically on a very low load factor, with a maximum use of the water equal to from two to three times the minimum flow. In irrigation districts however, it is necessary to build a storage reservoir below the power-house as well as above, in order to equalize the delivery of water to the ditches. By a proper combination of water-power plants (some with storage, others without), and a steam plant, all proportioned properly in relation to one another and to the load factor, it is possible to utilize every cubic foot of the water in the minimum season and to obtain an economy that is greater than either by steam alone or water alone. With such a combination, the water-power stations which have no storage can always be run at full load; and when water is scarce, the steam plants can be run at full load all the time and the peak can be taken by the water-power storage plant; whereas when water is flush the steam plants can be used for peak loads and emergencies only or can be shut down altogether. This principle can be extended beyond the fluctuations of a day, to the variations of a season or a year, and advantage can be taken of the fact that the low-water season of one stream does not coincide with that of another.

All this is being done in Utah, and during low-water seasons not an available drop of water is allowed to pass the Utah Light and Railway Company's power-houses without generating power, and that without interfering with irrigation.

The load factor of a mixed system of lighting, street railway and general power and mining service is not higher than 35 to 40 per cent and the tendency is not upwards. Even in smelters or mining camps where operations are carried on day and night the load factor is never much greater than 40 per cent; and while flour mills, pumping plants and some other operations may be continuous, there are always many intermittent services to affect them. It is this low load factor that limits the economical distance of power transmission more than anything else.

4. Speed Regulation.

Good speed regulation is absolutely essential to the success of a large power system, but it is dependent on the ratio of the total variations to the total load to a much greater extent than engineers generally care to admit. In small systems supplying power for very variable loads, goods speed regulation is hard to obtain with the best of governing arrangements. In large mixed power systems, however, conditions are conducive to steady speed, for though variations of load produced by street railways, elevators, hoists, etc., may be large and rapid, no change in speed can occur without changing the speed of every generator and motor and every piece of machinery on the system. In addition to this great total inertia, every change in speed of machinery is accompanied by a corresponding change in load, which is another factor tending to constancy of speed. On the other hand a large motor load introduces variations very great in proportion to total load during the dinner hour and at starting time in the morning.

In every steam or water-power plant there is a certain time limit between the variation of the load and the application of the power to meet it. This time limit is dependent upon the design of the governor, the inertia of the moving parts and the inertia of the steam or water. When operating plants in parallel, the inertia of the moving parts is the inertia of the whole system.

If a number of power plants operating in parallel were each equipped with the same kind of governor, each governor being adjusted to act on the controlling mechanism at the same time, it would be found that an increase of load would be first taken up by the steam plants, next by the water-power plants which were running on a constant stream with impulse wheels and deflecting nozzles, next by turbine plants with short pipes and ample forebay, and a long time after these, by impulse wheel or turbine plants where the regulation was performed by varying the velocity in long pipes. In order to make such an aggregation of plants govern simultaneously, so that each should take its share of load variations, it would be necessary to adjust the governors of all to the time limit of the slowest plant. In practice it has been found almost impossible to do this, and it will generally be found that the governing of a system of this kind is done from the largest water-power plant, or by a steam plant, or possibly by both. When a steam plant is running in parallel with water-power plants it is

generally necessary to have an adjustable dashpot on the governor to make the action slow, otherwise the steam engines will have to take up all the variations.

The solution of a difficult governing problem is now being attempted on the Telluride Power and Utah Light & Railway Company's systems which are paralleled together at Salt Lake City. It is required to deliver a constant amount of power from the former to the latter system, while at the same time each has to be governed for its own variable load. To do this with speed governors alone is a physical impossibility, for if all the governors could be adjusted to work within the same time limits the aggregate load variations of the two systems would be shared in proportion to governing capacity on each; while if the governors are not adjusted to work together, the quickest acting governors will take up the total variations on both systems. In either case there must be a variation in the power passed between the two systems. The problem might be solved by governing each system by independent electric governors, regulating in accordance with the variations of load on each system respectively. The arrangement of lines and distributing points makes this impracticable however. The only practical solution of this problem lies in the direction of increasing the amount of power delivered from the one to the other system until the variations caused by the governors bear a small ratio to the total. This problem may at any time become important to two large systems operating in adjacent territories.

5. Voltage Regulation.

The requirements for good voltage regulation on a large system running several plants in parallel are:

1. Good speed regulation.
2. The control of the whole system by one engineer operating from the main receiving and distributing center.
3. Good inherent regulation of all generators.
4. Lines of ample carrying capacity and small drop.
5. Ample transformer capacity at all points where inductive apparatus is used.
6. Low-tension distributing systems laid out for small drop in feeders, transformers and secondary mains.
7. The proper control of idle currents between stations.

8. The regulation of the power factor, on stations or on distributing system.

If these points are all attended to, good service can be given with a mixed load consisting of lighting, railway and power service; if any one of these is neglected, bad service must result on part, if not on the whole, of the system. The first and second requirements have already been discussed here. As regards the fourth requirement it may be pointed out that a transmission system having a large drop is justified only when the load is constant and the loss of power immaterial from a financial point of view. The fifth requirement is also fully appreciated now and all transmissionmen know by experience the importance of providing ample transformer capacity for induction motors which have to be started against load. With a given transformer capacity, the resistance-in-armature type of motor will start against a much heavier load than the squirrel-cage type, simply because the large starting current of the latter type reduces the voltage so much more than the small starting current of the former. In regard to the sixth requirement it may be stated that automatic feeder regulators of the three-phase induction type are being used with satisfactory results for regulating the 2000 and 4000-volt feeders in Salt Lake City. These regulators not only compensate for drop in feeders, transformers and secondaries, but also for speed variations caused by slight accidents or short-circuits on the system.

A great deal might be written on the subject of the seventh and eighth requirements. The operating engineer at the main receiving center should have the control of the voltage, while the power-house operators should take care of the speed. In a mixed system of lighting, railway and power service, the maximum loads at different points of the system occur at different times. Consequently it has been found best to carry approximately constant voltage at the receiving stations, to compensate at the power-house for drop in transmission lines only, and to compensate for variations of drop on the distributing feeders by regulating apparatus at the receiving end. No special difficulty has been found in regulating for a mixed load of lights and induction motors. A variable load driven by an induction motor has a useful tendency toward self-regulation for the low-power factor at light loads causes nearly the same drop of volts as the high-power factor at full load.

A line of great capacity, such as the Telluride Power Company's

40,000-volt lines, requires a heavy inductive current at light loads to compensate for the rise of volts due to the capacity. On a single 80-mile line from this company's Logan power-house, delivering 750 kilowatts at Salt Lake City, at a power factor of 100 per cent, the power factor at the power-house is about 60 per cent.

On a mixed system, the power factor can be kept at any value between 90 and 100 per cent by the use of synchronous motors driving railway generators; but for the regulation of voltage, synchronous motors are not of much value unless used for that purpose alone, because when loaded with work current they have not sufficient current capacity for regulating. Unless synchronous motors are under the control of the power companies' operators, pumping and other regulating difficulties will be caused by wrong adjustment of exciting current.

Sixty-cycle rotaries are too sensitive to be used as regulators and to operate them in parallel without pumping, variations of speed and voltage must be very small. If any trouble occurs on a 60-cycle system it is generally aggravated by rotaries.

When operating in parallel, cross-currents between power-houses introduce conditions which may seriously affect the voltage regulation. If the exciting current of the power-houses is not properly adjusted, some will tend to produce higher voltage at the receiving end than others and idle currents will flow which will be lagging with respect to the former and leading with respect to the latter. The amount of these currents is dependent upon the relative difference in excitation, the load and the line constants. These idle currents may be eliminated in two ways; first, by adjusting the excitation of the several power-houses; second, by voltage regulators placed in circuit between the transmission lines at the receiving end, which can be adjusted to maintain that difference of voltages between lines which is required to prevent the flow of cross-currents.

Formerly the desired results could only be obtained by trial and experience. Now, however, by the use of power-factor meters on every generator on the system, the adjustments can be made with accuracy to meet any conditions of line or load. The power-factor meter has become an indispensable adjunct in the operation of all synchronous machinery on large systems.

The fact that the excitation of the power-houses depend on variable conditions on different parts of the system, seems to point

to the impracticability of using any automatic device for controlling exciting currents on large parallel systems.

6. The Arrangement of Transmission Lines, Transformer-houses, Etc.

While break-downs on transmission lines cannot be altogether prevented, it is possible to so nearly approach continuity of service that even the exacting requirements of a smelter can be met. This can only be done, however, by the exercise of the greatest care in

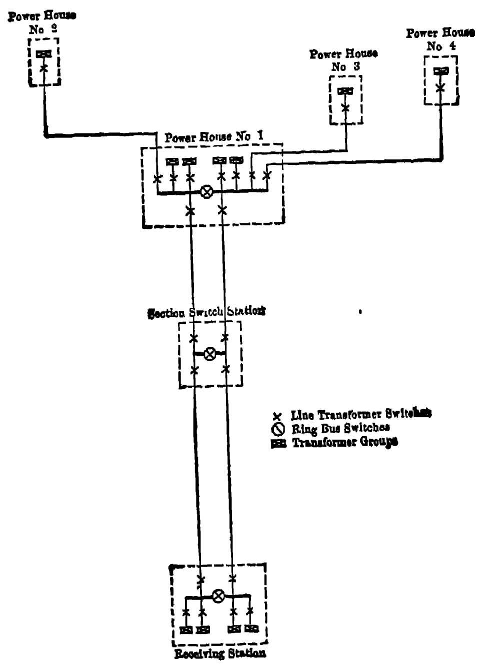


Fig. 1.—General arrangement of high tension lines and switches for a number of power houses in same locality supplying power to a distant distributing center

the arrangement, construction and operation of the switching apparatus, transmission lines and transformer-houses. Nothing but failure will result if the transmission lines are not mechanically strong and well insulated, but good construction and duplication of lines and power-houses are of little avail unless the general layout of the lines and switches is of the simplest kind.

The trend of experience in line construction points to the use

of long spans of stranded copper with steel towers, porcelain insulators and rigid iron pins. There is a tendency to increase rather than to diminish the cost of construction, so that the cost of copper and, therefore, the choice of voltage, is by no means the greatest consideration in designing transmission lines. In locating a line it should be remembered that accessibility for patrol and repairs is more important than saving of distance. Transmission lines should be constructed so that nothing but outside interference will break them down. Between every important power-house and distribut-

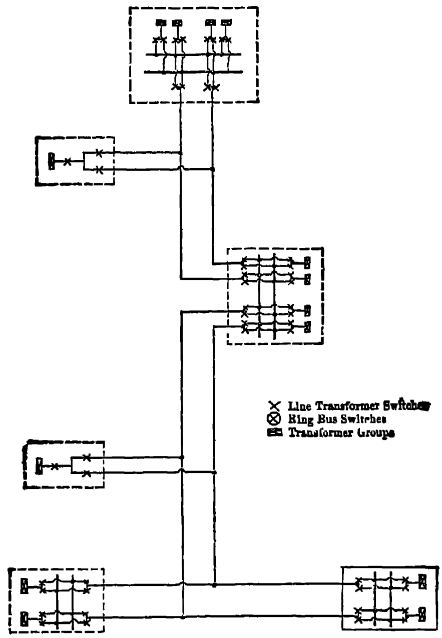


FIG. 2.—GENERAL ARRANGEMENT OF HIGH TENSION LINES AND SWITCHES FOR A NUMBER OF POWER HOUSES AND RECEIVING STATIONS SCATTERED OVER A LARGE DISTRICT, LAID OUT ON DUPLICATE MAIN SYSTEM.

ing center there should be at least two lines, and sometimes two routes are advisable. On very long transmissions there should be section-switch stations (see Fig. 1) so arranged that portions of the line can be cut out for repairs without putting the whole line out of service. Unless this is done, each line must be designed to carry the maximum load transmitted with a small drop. Very long lines will seldom be financially justified unless a very considerable business can be done on the way. On the other hand, isolated sub-

stations on an important line are a serious detriment to service, unless the business done will justify a good section-switch station with an operator constantly in attendance.

The best arrangement for the transmission lines of a system operating many plants in parallel depends on the location of the power plants with respect to the present and prospective points of distribution. In systems consisting of several power plants located near one another and transmitting power to a distant point, the

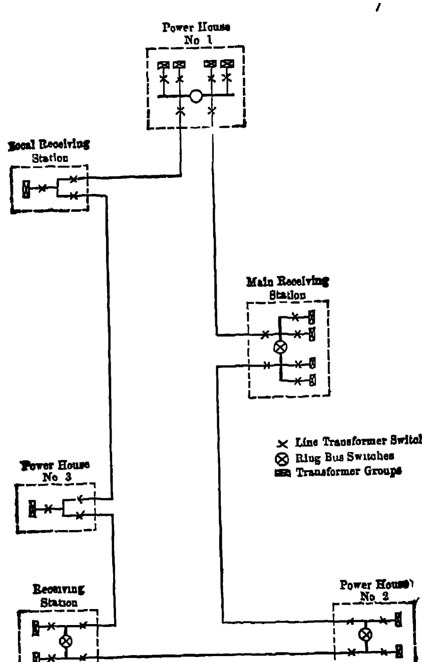


FIG. 3.—GENERAL ARRANGEMENT OF HIGH TENSION LINES AND SWITCHES FOR A NUMBER OF POWER HOUSES AND RECEIVING STATIONS, LAID OUT ON THE RING MAIN SYSTEM.

arrangement does not materially differ from that of a single power-house. In this case it is usually best to treat the smaller plants as generating units of the most important power-house, as represented in Fig. 1. In systems where the power-houses and distributing points are scattered, the transmission lines will take either the form of a duplicate bus to which will be connected all the power-houses and receiving stations, as shown in Fig. 2, or else will be laid out in the form of a ring main as shown in Fig. 3.

Whether for station bus-bars or transmission lines, the ring main divided into sections as shown in Figs. 3 and 5 has been found to be the most practical arrangement to operate. If the business between any two points on the ring becomes so important as to warrant a duplication of lines between them, the system can generally

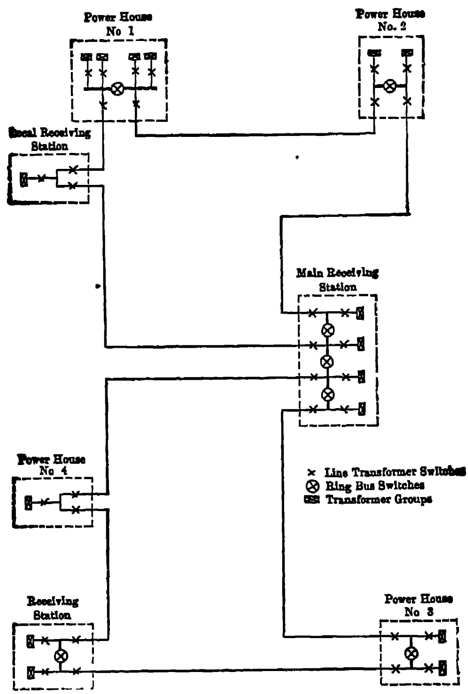


FIG. 4.—GENERAL ARRANGEMENT OF HIGH TENSION LINES AND SWITCHES FOR A NUMBER OF POWER PLANTS AND RECEIVING STATIONS, LAID OUT ON THE RING SYSTEM, WITH TWO RINGS PASSING THROUGH THE MAIN RECEIVING STATION.

be resolved into two or more rings all passing through the important center as shown in Fig. 4.

Fig. 5 shows the ring system as applied to power-houses and transformer stations, from which it will be seen that it is practically equivalent to a group-switch system. With this layout any group of transformers, feeders or generators with its corresponding transmission line can be separated from the rest of the system in an instant by opening the high and low-tension ring bus switches. This arrangement in a transformer-house is ideal when each group

of transformers has capacity to carry all the power that can be delivered over the corresponding line.

Short-circuits on transmission systems may be caused by failure of transformers, lightning arresters or line insulation, or by outside interference by nature, man or beast. Their frequency is a measure of the efficiency of construction and management. They will vary in severity from those which cause just a flicker in the lights to those that may shut down a large station. Short-circuits on the low-tension side of receiving stations will never seriously affect the system as a whole. Short-circuits on transmission lines which can be burnt off, will seldom throw power-houses out of step and should cause very little interruption. Even very severe short-circuits will not throw power-houses out of step unless occurring on the line between them or very close to one of them. In a well-laid-out parallel system no failure on transmission lines can cripple the whole system, and rotaries and motor-generators will

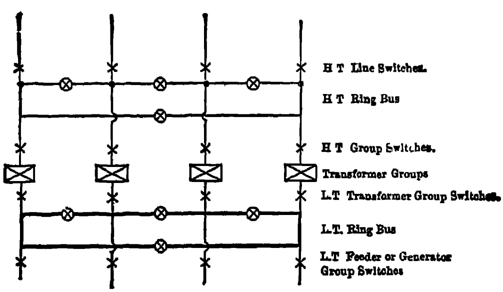


FIG. 5.—GENERAL ARRANGEMENTS OF HIGH-TENSION AND LOW-TENSION BUS BARS AND SWITCHES FOR GENERATING AND RECEIVING STATIONS, LAID OUT ON THE RING SYSTEM.

stay in step through many shorts. It is when a short occurs which cannot be burnt off, or which throws power-houses out of step, that the efficiency of layout and operating staff is tested. It is not the short-circuit which hurts the service, but the stopping of machinery and time taken to get under way again.

Under normal conditions there is no difficulty in cutting generators and synchronous motors in or out of service, or in synchronizing power-houses on lines at any point in the system, but when everything is thrown out of step or stopped by a severe short-circuit, synchronizing is altogether too slow. All synchronous motors should be self-starting from the alternate-current end, or at least

should be designed so that the alternate current can be switched on after they have been given a preliminary spin. Two-hundred horse-power synchronous motors have been regularly started without any compensators for a long time in Salt Lake City. Power-house generators can be synchronized very rapidly, but time can be often saved by running them to speed approximately and switching on to the live circuit before closing the exciting circuit. In the Los Angeles system, it is a rule to open the exciting circuits on all generators and synchronous motors, except at the largest station, whenever a short-circuit occurs. As soon as the trouble is cleared, the main station generators bring up speed and volts, the other generators and motors are pulled into step and the station operators close the exciting circuits. This is a very good method of starting, but is not applicable to every condition.

It is in clearing short-circuits on transmission lines, that the ring system as illustrated in Figs. 1, 3, 4 and 5 is so superior to the duplicate bus system shown in Fig. 2. When a short-circuit occurs which does not clear itself at once, the ring bus switches can be opened up so as to resolve the system into two or more separate parts complete with their own power-houses, lines and loads. This immediately locates the trouble, the short-circuited line can be quickly cut out, and the load on the short-circuited section transferred to the adjacent portion of the ring without any delay for communicating between stations. Automatic circuit breakers can be used for these ring bus switches with great advantage, but except on unimportant branch circuits, they can be used nowhere else on a transmission system of this kind. Reverse-current circuit breakers for cutting out a short-circuited line will not work, for under normal conditions on a parallel system power may be coming from either direction at any time.

High-tension air switches have played an important part in the building up of transmission systems. They can be made simple, strong and safe for outdoor operation even at 40,000 volts, but at best they are makeshifts and must be replaced by oil switches which have proved reliable in service on the highest voltage now in use.

So far as the operation of large parallel systems is concerned, it appears that the question of transformer windings, star or delta connections and grounded neutrals are likely to be settled by circumstance rather than by design. A delta-connected system

can operate without a grounded neutral, a star-connected system cannot. Large parallel systems are almost certain to have both star and delta-connected transformers working together; and questions of cutting out one transformer in a bank, or of abnormal voltage caused by break-downs, become unimportant on account of the large number of banks in use. The fact that with a grounded neutral, the break-down of a single insulator makes a short-circuit, is not important if the lines are properly laid out, and when break-downs occur the quicker something burns off and the line is cut out the better.

In the layout of transformer stations, space and simplicity of wiring is a greater protection than all the fireproofing yet devised. Lightning arresters, transformers and switches should as far as possible be in separate fireproof rooms. High-tension wires should be covered with high-volt insulation and supported on insulators.

7. Lightning and Other High-Tension Disturbances.

In the first few years of long distance transmission high-tension disturbances due to switching, short-circuits, etc., were little understood and not of much importance. As systems increased in size and were paralleled together, however, these disturbances increased in frequency and severity and it was found that the earlier transformers were not sufficiently well insulated to withstand the shocks. Short-circuits on large systems operating in parallel are liable to be more severe than on single systems, because power is supplied from both ends of the line.

Fortunately however, the disturbances due to switching and short-circuits, etc., are now pretty well understood and have definite limits, and no trouble need be feared from them if the transformers are properly wound and insulated and lightning arresters and oil switches are carefully installed.

Disturbances due to gradual change in atmospheric conditions and differences in elevation of lines, etc., are well cared for by modern lightning arresters without disturbing the system. The limits of the high-voltage surges resulting from the sudden release of static charges on the lines are determined by the insulation of the weakest part of the line affected, which should of course be the lightning arrester. Except for the fact that a large parallel system is exposed to more changes in atmospheric conditions than systems with short lines, there is no evidence to show

that the disturbances increase in energy beyond what should be expected from the increased capacity of the lines.

The disturbances due to short-circuits, switching and static charges are, however, trifling, compared with those that may be set up by lightning discharges. It must be confessed that no real progress has been made in apparatus to protect against these disturbances, and today the choking effect of the transformers and the high insulation of the windings, both of the oil and air-blast type, is their own best protection. This has been demonstrated over and over again by discharges from terminal wires of transformers to case, across sparking spaces many times greater than the total gaps on the lightning arresters, and in spite of the protection of choke coils of the most recent design.

The disturbances set up by lightning discharges range in severity from those that can be easily taken care of with existing apparatus to those that may wreck a station. The latter seldom occurs, but when they do, the result is like an explosion and no plant in a thunderstorm district can claim to be protected. A lightning discharge which strikes the line shatters insulators and poles and is intensely local in its action, for the simple reason that the voltage is so high that line insulation must break down close to the point of discharge.

The sudden raising of the voltage of the line, to the break-down point, will, however, send static waves along the line. The voltage of these waves and the distance at which they may be effective depends chiefly upon the strength of line insulation. With wooden pole lines, the insulation to ground may be very high in dry weather and under these circumstances the static wave may be of very high voltage. Some waves have passed from line to ground across a 12-in. dry air-gap on a 40,000-volt line. This has occurred on several occasions without damage to transformers.

It follows, from what has been written above, that the extending of a system to cover a very large area, while exposing it to the action of more storms, and consequently increasing the number of the disturbances, does not by any means increase the severity of the secondary disturbances which are limited by the insulation of the line.

Transformers should be insulated between layers of high-voltage windings to withstand shocks that will break down the line insulation. Money spent on extra insulation inside the transform-

ers will probably bring better returns than the same expenditure on outside protective devices.

It seems probable that steel towers will be ideal for protecting stations and apparatus from the more severe effects of lightning disturbances.

There are many other points bearing on the subject of this paper to which a reference only can be made here.

While it is generally cheaper to store water-power than electricity, some transmission plants cannot give satisfactory service without storage batteries, and on nearly all it pays to use them to a greater or less extent both on account of regulation and emergencies.

It will be asked whether it pays to operate so many plants in parallel instead of generating power in one or two large plants. This depends entirely on local considerations, and the answer is sometimes yes, sometimes no. When there are convenient water-powers it will nearly always be found that a combination of water-power and steam gives the most economical results. The opinion, however, cannot be too strongly expressed, that a depreciation charge of 10 per cent per annum, at least, should be made on the whole cost of construction of both steam and water-power plants. The neglect to do this may be hidden by reorganizations or abnormal growth of business, but it means financial failure sooner or later. It is extraordinary how often people, who ought to know better, will shut their eyes to this fundamental law of engineering finance.

As regards the bearing of parallel operation on future developments, it may be pointed out that it would be possible to-day to operate a string of steam and water-power plants in parallel from the Atlantic to the Pacific Coast and to supply power to trunk railroads with so few interruptions that train service could be as punctual as it is today on steam roads.

The author's acknowledgments are due to many engineers who by advice, suggestions and investigation have helped in the solution of many difficult problems but most of all are they due to the members of an operating staff upon whom has fallen the burden of all the troubles and difficulties experienced in the course of nine years' work in transmission in the State of Utah.

Discussion.

Chairman Scott: The papers of Mr. Hancock and of Mr. Haywood are open for discussion. They reveal another side of station operation which men in the laboratory or in the engineer's office would hardly discover. They show the workings of the operating system, Mr. Hancock's paper in particular dealing so much in detail with the operating force of a large system, throws an excellent light on that side of the problem. Mr. Hayward has done just what he was invited to do and has given some of his experiences from his own work on the system with which he is connected.

Mr. P. N. Nunn: While the problem of lighning arresters for high voltages has not been fully solved, it seems hardly fair to say that nothing has been accomplished. While arrester service in Utah has been far from satisfactory, no high-voltage transformers have ever been lost, and but trifling repairs occasioned through lightning. If it is possible, as suggested, to get higher insulation for a slightly increased first cost, without sacrifice in the characteristics of the transformer, it is undoubtedly wise to do so. Quite aside from lightning, however, effective and reliable arresters are needed to protect from those other disturbances incident to long distance transmission, which interfere with the use or perfect operation of automatics and similar devices. Mr. Hayward's paper advises "The control of the whole system by one engineer operating from the main receiving and distributing center," and says "The operating engineer at the main receiving center should have the control of voltage, while the power-house operator should take care of the speed." This strongly suggests that in the case of a power company with many customers, its plant should be operated for or by some one customer. In the present instance, the producing system is operated for constant voltage, and the customer has been advised and is now preparing to receive his power through induction regulators, which will put within his reach the control desired both as to voltage and power factor.

Mr. C. S. Ruffner: Mr. Nunn has asked for a statement of the results of this experiment. The experiment has not been carried far enough along yet to give any very complete results. A small regulator was put on one of the circuits connecting the two systems, being adjusted for only the part of the load that the regulator could take care of, and it showed such improvements in the power-factor that we feel there will be no doubt about the feasibility of controlling the entire load with a regulator of this kind. The difficulty has been that the ratio of the transformer connections between the two systems has been such that it made the receiving system take a leading current, which was, of course, added to the charging current of the lines, and gave at the generating station an extremely heavy current overload. By means of this regulator, bringing the voltage of the two systems into the proper adjustment, it will be possible to let the charging current from the one system supply the lagging component of the load on the other, giving more nearly a unity power factor at all generating stations, and consequently giving a little better voltage regulation on that account. The experiment will be very interesting, although we have no doubt about what is going to happen

after the regulator is installed The regulator that is to be ordered is of the three-phase induction type, adjusted by hand. At present we have made no arrangement for any automatic adjustment, on account of the difficulty of being able to tell by the regulator which way it is to be moved; that is, the regulator is not able to determine which system is delivering too high a voltage when the voltage at the regulator is too high. Any automatic adjustment would, of course, have to be made by a device controlled by a power-factor indicator, and it is probable that the regulator will have to be adjusted so that the load may be taken at different power-factors at different times of the day, varying with the power-factor of the different classes of load at the different hours. It is the ordinary commercial regulator; the small one that was put in was what is known as the I. R. T. regulator, and worked very nicely with a small load. The only effect of this regulator is to give a controllable variation in the ratio of transformation, and the regulator seems to offer the most convenient way of varying this ratio, rather than having any variable taps on the transformer. Of course, that could be accomplished by the variation in the transformer taps.

CHAIRMAN SCOTT: One word in regard to the operation of the two systems which may clear up a point concerning which a member has made a query. The two systems may, in a way, be regarded as having the same function as two alternators running in parallel. Those two alternators are to deliver power to the system. The power that they deliver will depend upon the power that they get, which in this case will depend upon the position of the governors of the waterwheels. The amount of power given by the water to the wheels goes through the apparatus and into the electric system. Conversely a change in the power which is delivered by one alternator, or by the other, or by one system of power houses, or the other system of power houses, will depend on the amount of power developed by the waterwheels, so that the governing of power must be done in the hydraulic part of the system. It cannot be done through speed governing of different parts because all the parts must run at the same speed. Again, when two alternators are running in parallel, they may deliver a leading or a lagging current. They may deliver the out-of-phase-current equally, or one may deliver more than the other. If there are lines to be charged, one generator may do all the charging or the two may work together. If there be induction motors to be supplied with lagging current, one may supply all the current or the other may supply all the current or the two may work together. That adjustment depends not on waterwheels but on field charges and the voltages produced. And to make one generator or the other carry more or less of the out-of-phase-current, it is necessary to change the voltage through adjustment of the field charge. Now these two systems are operating conjointly in one sense and independently in another. If one is to be operated at a little higher voltage than the other when the two are linked together, the only way to link them satisfactorily is by transformation; that is, through a transformer, by letting one run at one hundred per cent and the other at say a-hundred-and-ten per cent and making the adjustment through the regulator; and as that adjustment changes from time to

time through the day, it is a matter which must be under control. If independent regulation of voltage on the two systems is attempted by other means, the out-of-phase-current between the two systems is apt to be troublesome.

Mr. NUNN: It may make this matter clearer to explain that the line in question is nearly 200 miles long, having a large charging current, supplied equally, we may say, by generating stations at either end, so that, at the center point — Salt Lake City — only work current necessarily flows. Although the Salt Lake system has a large lagging component within itself, it may take its purchased power at unity power factor, but if its voltage drops below that of the transmission, this entire charging current may be drawn from the terminal stations to the Salt Lake system, to combine with the lagging component at that point, thus raising the power factor at all power houses, but reducing the power factor of the purchased power. The same thing may go further, and in either direction, and under normal operation the conditions are very unstable. This may be entirely controlled through proper attendance at the regulators.

Mr. R. S. HUTTON: I do not quite understand this. If the delivered load on one system has a heavy lagging component and the other has a heavy leading component, putting the two together, it seems to me instead of lowering the power factor on both of them — in other words, giving them both heavier current — it would result in counteracting one another, and they would both have less current than before.

Mr. NUNN: It is true that under a certain fixed condition there might be unity power factor at all generating stations. In this particular instance, however, the power company has other lagging current to provide for which takes up all the charging current, and therefore has contracted with this customer to maintain a unity power-factor.

Mr. HUTTON: I might mention one other point. I understand the idea they have in getting the two voltages of the receiving stations the same, is that they can put them together without having one system disturbing the voltage of the other. We are practically doing the same thing, only instead of using the induction regulator, we prefer to use the regulator heads on the transformers, for the reason that the induction regulator is a very expensive machine, something like $13.00 per kilowatt for a 200-kilowatt size.

CHAIRMAN SCOTT: We have to regret that several papers on the programme of Section D have not appeared and are not now expected. The paper by Mr. Mershon, the Delegate of the American Institute of Electrical Engineers to the Congress, is not here and we will consider that paper read by title and it will appear in the Transactions. If there is nothing more to be said before the adjournment of this Section I declare this Section adjourned.

Dr. F. A. C. PERRINE: Before we adjourn I wish to offer on behalf of Section D a vote of thanks to our officers for carrying on their work under what has been apparent to us all, very decided difficulties, and I think the success of the session has been entirely due to the energy and ability of our officers. Consequently I wish to propose a vote of thanks to the officers. (Unanimously carried.)

THE MAXIMUM DISTANCE TO WHICH POWER CAN BE ECONOMICALLY TRANSMITTED.

BY RALPH D. MERSHON, *Delegate of American Institute of Electrical Engineers.*

As transmission voltages, actual or proposed, become higher and higher and transmission distances reach out farther and farther, it is interesting and profitable to inquire into the probable maximum distance to which power will be commercially transmitted. As with most engineering enterprises, the limitations will come through economic conditions, and the greatest distance to which power will ever be transmitted will be the greatest distance through which it can be economically (using the word in its broad sense) transmitted.

In endeavoring to make such forecasts as will be here attempted, it should be borne in mind that every limitation which we put upon ourselves by the assumptions necessary in order to obtain definite representative figures, adds to the chance of our forecast proving erroneous. For instance, the first assumption we must make is that in the future power will be transmitted in the same way as now. This may not hold. There may be devised some other and better way not involving the use of transmission lines. Such, however, does not appear probable. Other assumptions which must be made as to methods of construction being the same as, or similar to, those at present in use, may be eventually so modified by skill and experience as very materially to change any conclusions which may be arrived at now. This is less improbable. Conditions, industrial and financial, may so change that the constants now assumed as fixing costs, interest, etc., will be materially modified. This is very probable. Finally, it is certain that with the course of time the value of power will increase, and this will materially modify any figures at which we may now arrive. The present conditions of practice and possibility are sufficiently definite, however, to warrant a forecast with the expectation that it will be applicable, approximately at least, for some con-

siderable time to come. At any rate, the method of treatment of the subject herein adopted will, with suitable changes in the value of constants, apply so long as present methods of power transmission obtain.

The elements which, in the broadest sense, limit the distance to which power can be economically transmitted, are two—the cost of power at the generating station and the price which can be obtained for the delivered power. The difference between these two elements must cover the cost of transmission, the interest on the investment and the profit. The cost of transmission comprises the loss of power in transmission, the cost of operating, the cost of maintenance and repair. The value of the sum total of the interest which must be paid upon the investment, and the minimum profit which is considered satisfactory, will have much weight in determining the limiting distance of transmission. The less this sum is the farther power can be transmitted; a low interest rate and a low rate of dividend will, therefore, be conducive to long transmissions.

Let us consider in a general way the manner in which the investment in a transmission plant and the annual charges and expenses in connection with the plant vary with different outputs, voltages and distances of transmission. For a given voltage, drop and distance of transmission, the cost of all the apparatus and equipment, except the line conductors, will increase more slowly than the output of the plant. That is, the greater the output of the plant the less the cost per kilowatt of all the equipment, except the line conductors. This will be true of the operating expenses also. Therefore, since the interest charges and the charges for depreciation and repair are dependent upon the investment the greater the output of the plant the less will be the quantities going to make up the annual cost per kilowatt of transmitting power, except those depending upon the line conductors. Since the weight of the line conductors, under the conditions assumed, will vary directly as the amount of power transmitted, those elements of the annual cost per kilowatt depending upon the line conductors will be practically constant for all amounts of power transmitted, and can not be materially reduced by increasing the amount of power transmitted. With the same voltage, economic drop and output, the elements of annual cost per kilowatt due to the line structure (pole line) and to its extent (patrolling, etc.) will increase directly as the distance. But, as outlined above,

any increase of cost in line structure due to increase in distance can be offset by increase of output. On the other hand, the weight of the line conductors increases as the distance (for the same economic drop—as the square for the same drop) and the elements of annual cost per kilowatt due to the weight of the line conductors will, therefore, increase as the distance, no matter what the output.

It appears, therefore, that all the elements in the annual cost per kilowatt for transmitting power, except those dependent upon the line conductors, may be indefinitely reduced by increasing the amount of power to be transmitted. The annual cost per kilowatt due to the line conductors can not be so reduced. It can be diminished only by such other means as will reduce the first cost of the conductors. As the first cost of the line conductors can be reduced only by increasing the voltage of transmission and as there is a limit to which such increase can be carried, it follows that *the limiting distance to which power can be economically transmitted will depend, finally, upon the cost of the line conductors and upon this alone.* The limit of voltage referred to is not necessarily that due to physical considerations, such as difficulties of construction, air losses between conductors, etc.; for, leaving such matters out of consideration, it is easy to imagine the voltage carried to such a high value as will reduce the line conductors to the point when the increased cost of transformers and insulators, due to a further increase of voltage, will overbalance the saving in the line conductors, due to such further increase.

It will somewhat simplify the treatment of the subject if the interest charge be included as a part of the cost of transmission, and profits be represented by a percentage on the investment. This course will, therefore, be pursued. That is, it will be assumed that in the cost of transmission is included the interest on the investment (bond interest), and that over and above this cost there must be earned a certain percentage, which percentage will represent profits (stock dividends). In addition the following assumptions will be made.

Power purchased at low-tension bus-bars of step-up transformers and sold at outgoing bus-bars of the step-down station.

Frequency of transmission not less than 25 cycles nor more than 30 cycles as being the limiting frequencies which, while favorable to the transmission of power, are yet suitable for almost all purposes to which power can be applied.

Idle synchronous motors at step-down station to correct for power factor, the average power factor of the line being held as near unity as possible. In the plants of large output dealt with below, the possible approximation to unity power factor will, in spite of the line-charging current, be sufficiently close to, for practical purposes, justify the assumption of unity power factor.

That no matter what the capacity of the plant, there will be three transmisson lines, each capable of carrying one-third the load.

That the power factor of the load supplied will be 0.8.

That no matter what the size of the plant, the number of transforming units at each end of the line be 18, each transformer being normally worked at five-sixths of its rated capacity, so that one bank of three may be cut out, if need be.

That no matter what the size of the plant, the number of corrective synchronous motors will be six, each being worked at five-sixths of its rated capacity. The kilovolt-ampere capacity of these synchronous motors must, for a load power factor of 0.8, be equal to three-fourths of the kilowatt capacity of the load carried by the plant.

It is evident that the number of units must be considered as the same for plants of all capacities in order to take full advantage of the decrease of cost per kilowatt, due to increase of capacity.

The pole lines will be assumed as constructed with 12 steel towers to the mile.

Ideal conditions will be assumed throughout consistent with delivering reliable and cheap power. Since the object is to determine the *maximum* distance, the factors fixing commercial costs of apparatus will be taken at the lowest values likely to obtain.

Later on in this paper general equations are derived expressing the relations between the distance of transmission and the quantities which govern it. By making assumptions, in addition to those mentioned above, as to the values of the various co-efficients in the general equations and as to the purchase and selling price of power, the curves of Figs. 1, 2, 3, 4 and 5 have been obtained, which are given and discussed here instead of at the end of the paper. Fig. 1 shows the relation between the distance of transmission D and the economical voltage E for different outputs W; that is, it shows the voltage which it is most economical to use for any given output and distance of transmission. Fig. 2 shows, in a corresponding manner, the economical drop. Fig. 3 shows the diameter of the conductors corresponding to the conditions of

Figs. 1 and 2. Fig. 4 shows the relation between D, the distance of transmission, and p, the percentage net profit on the investment for different values of output W and for the selling price of $34 per kilowatt per annum. Fig. 5, a curve obtained from Fig. 4, shows the relation between the distance of transmission and the output for a net profit of 12 per cent.

In obtaining these curves, the constants have all been given values

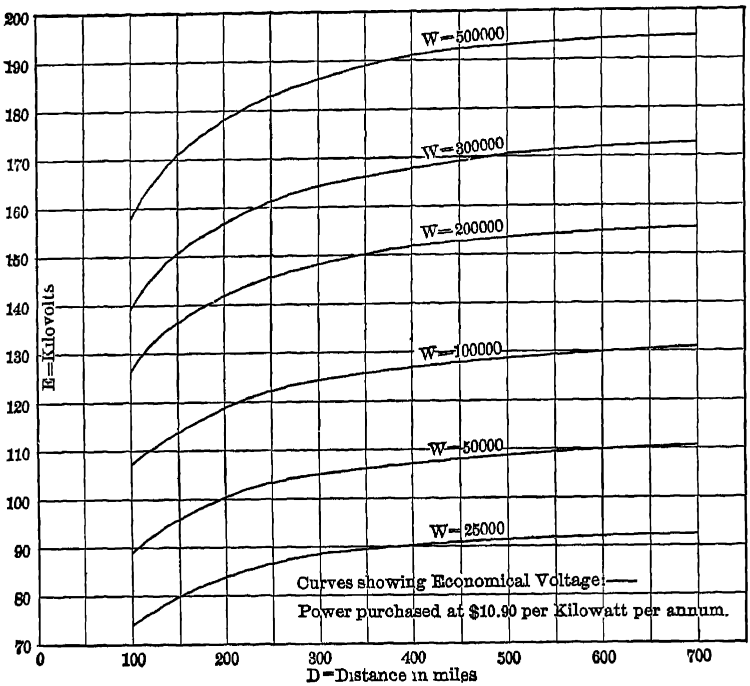


FIG. 1.

favorable to long transmission distances. The costs have been taken lower than those ordinarily current in the endeavor somewhat to anticipate possible future prices. Also, the cost of power purchased at the step-up station has been fixed at the very low figure of $10.90 per kilowatt per annum. These facts should be carefully borne in mind in considering the curves, which will all be more or less modified by changes in the quantities mentioned.

It is difficult to fix upon a figure for the selling price of the delivered power which shall be representative. Power prices are so dependent upon conditions, especially those arising from the

location and magnitude of the market and of the supply, that any figure chosen will be objected to by some as too high and by others as too low. The same condition applies to the price assumed as that paid for power at the step-up station, but in a lesser degree. The figure herein assumed as the price of the power sold, $34 per

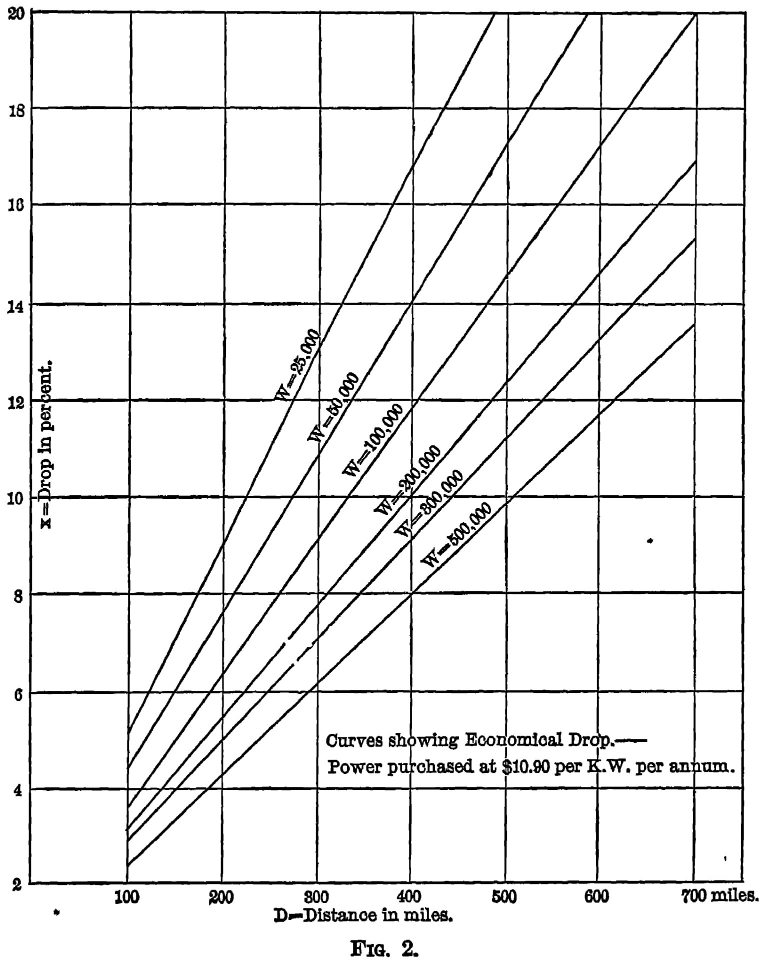


FIG. 2.

kilowatt per annum, is that which seems to the writer will be fairly representative, especially in the case of the large blocks of power. The writer does not, however, wish to be understood as committed to an opinion by the power prices herein, either in the case of pur-

chase or sale. The values taken have been chosen as being as nearly representative as possible of the best conditions which might obtain, favorable to long-distance transmission. If these figures should be criticized in about equal proportion from the standpoints

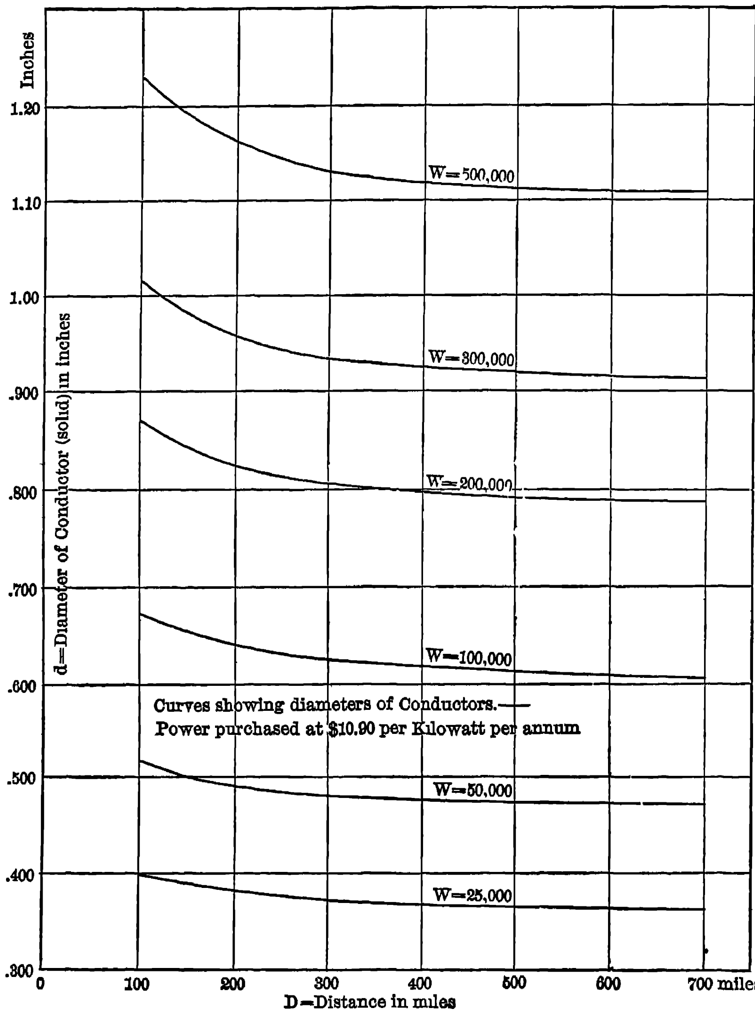


FIG. 3.

of being too low and too high, respectively, the object in choosing them will have been accomplished, since such criticism will be evidence of their fairness as a reasonable compromise.

The maximum amount of power dealt with herein, 500,000 kilowatts, is probably too high to be seriously considered at this time, but from 200,000 to 300,000 kilowatts is believed to be within the range of immediate future possibility. In a plant of this size it

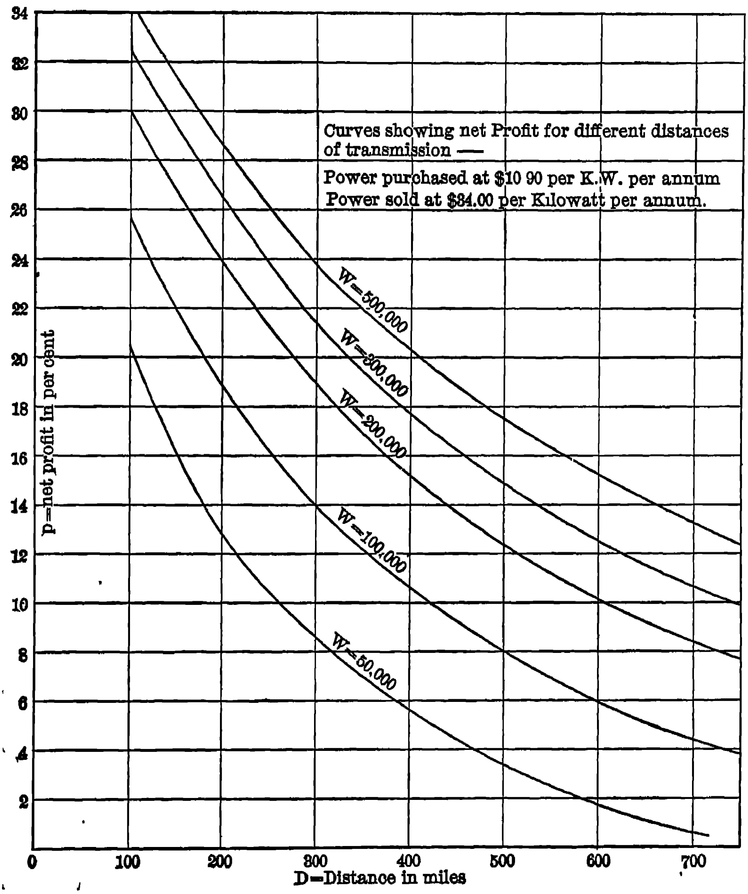


FIG. 4.

is probable that a net return of 12 per cent would be required, not alone for the purpose of dividends, but also as a protection to the bonds. Under these conditions Fig. 5 shows the distance of transmission to vary from 512 miles for 200,000 kilowatts to 623 miles for 300,000 kilowatts.

It appears from the preceding matter that, under the conditions assumed, the limiting distance of transmission will, for some time at least, be in the neighborhood of 550 miles.

It also appears that voltage limits will be fixed by economic conditions and not by conditions depending upon atmospheric losses.

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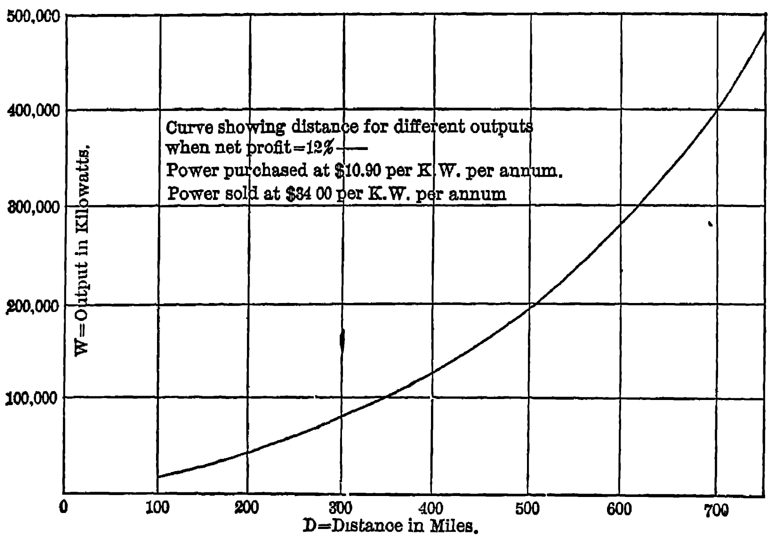

FIG. 5.

The analysis on which depends the general equations from which the preceding curves were obtained will now be taken up.

Let E = voltage in kilovolts delivered to step-down transformers.
D = distance of transmission in miles.
x = percentage of delivered power lost in the line.
e = efficiency of the whole system.
e_1 = combined efficiency of step-up and step-down transformers and synchronous motors.
d = diameter of line conductors in inches.
W = power, in kilowatts, delivered at the low-voltage bus-bars of step-down station.
c = cost, in dollars, per kilowatt per annum at the low-voltage bus-bars of the step-up transformers, of purchased power.

s = price, in dollars, received for power per kilowatt per annum at the low-voltage bus-bars of the step-down station.

h = a quantity which multiplied into c will give the cost of power at the high-voltage terminals of step-up transformers.

R = total interest, maintenance and depreciation charge per annum.

L = cost of labor for operating transformer stations and for executive and clerical services.

M = total investment.

C = total cost per annum of power delivered, inclusive of interest.

p = a percentage covering profit.

$e = \frac{e_1}{1+x}$ since $\frac{1}{1+x}$ is the efficiency of the line.

$\frac{Wc}{e} = \frac{Wc\,(1+x)}{e_1}$ = total amount expended per annum for power purchased.

Ws = total amount received per annum for power sold.

$$C = \frac{Wc}{e} + L + R$$

$$p = \frac{Ws - C}{M} = \frac{Ws - \frac{Wc}{e} - L - R}{M} = \frac{Ws - \frac{Wc\,(1+x)}{e_1} - L - R}{M}$$
$$= \frac{N}{M}. \qquad (1).$$

Now M is made up of

1). Cost of transformers.
2). Cost of transformer switchboard apparatus, cables, lightning protection, etc.
3). Cost of building and real estate.
4). Cost of insulators.
5). Cost of pole-line material and construction.
6). Cost of right of way.
7). Cost of corrective synchronous motors and exciters.
8). Cost of switchboard apparatus, cables, etc., for synchronous motors.
9). Cost of conductors.

Cost of transformers will depend upon voltage and output;

$f_1\,(E, W)$.

Cost of transformer cables and controlling apparatus will depend upon same quantities as transformers, but in a different way;

$f_2\ (E, W)$.

Cost of building will depend upon output;

$f_3\ (W)$.

Cost of insulators will depend upon voltage, diameter of conductors and number required, i. e., voltage, diameter of conductor and distance of transmission;

$f_4\ (E, d, D)$.

Cost of pole-line construction will depend upon diameter of the conductors and the distance. But the diameter of the conductors depends upon voltage, drop, output and distance, hence

$f_5\ (d, D) = f_5\ (E, W, x, D)$.

Cost of right of way will depend upon distance only;

$f_6\ (D)$.

Cost of synchronous motors will depend upon output only, since all other factors of cost will be fixed;

$f_7\ (W)$.

Cost of switchboards and cables for synchronous motor will depend upon output only;

$f_8\ (W)$.

Cost of line conductors will depend upon voltage, output, line loss allowed and distance of transmission;

$f_9\ (E, W, x, D)$.

The sum of these nine functions constitutes M, the total investment.

Now R (total interest and depreciation charge) depends upon all of the several quantities making up M.

In what follows, the numerical value of the constants are those taken for the specific problem treated herein.

Let $p_1 = .125$ = percentage of transformer cost for interest, depreciation and repairs.

$p_2 = .125$ = percentage transformer switchboards cost for interest, depreciation and repairs.

$p_3 = .075$ = percentage of buildings cost, for interest, depreciation and repairs.

$p_4 = .10$ = percentage of insulators cost, for interest, depreciation and repairs.

$p_5 = .125$ = percentage of pole line cost, for interest, depreciation and repairs.

$p_6 = .05$ = percentage of cost of right of way, for interest only.

$p_7 = .125$ = percentage of synchronous motor cost, for interest, depreciation and repairs.

$p_8 = .125$ = percentage of cost of synchronous motor, switchboard, etc., for interest, depreciation and repairs.

$p_9 = .05$ = percentage of cost of conductors, for interest, depreciation and repairs.

R = the sum of these percentages multiplied respectively into the several quantities to which they refer.

L depends only upon output, $f_{10}(W)$.

The numerical values given for the percentages p_1, p_2, etc., are those which will be used in the specific problem herein treated. The rate of interest has in all cases been taken as .05, so that by subtracting this from the above values the depreciation assumed in each case may be determined.

If there be substituted in equation (1) the values of M, L and R, as expressed by the above symbols, there will result an equation expressing in the most general terms the relations between the distance of transmission and the quantities which govern it. This substitution results in rather an unwieldly expression and will be omitted.

Before proceeding with the determination of the forms of the several functions indicated, it will be necessary to enter into a discussion of the relations existing between voltage and line loss, and the quantities governing them respectively.

Let q = that portion of the cost per kilowatt at the low-tension bus-bars of the step-down station, which is due to line loss and to interest on the value of the conductors; then, anticipating in part, the matter of a few pages further on

$$q = \frac{\dfrac{p_9 K_9 W D^2}{E^2 x} - hc\,Wx}{W}$$

in which $\dfrac{p_9 K_9 W D^2}{E^2 x}$ is the interest on the conductors and $hc\,Wx$ the cost of the power lost in the line.

Setting the first derivative of this with respect to x equal to

zero, in order to determine the minimum value of q, we find the well-known expression for economic drop

$$X = \left(\frac{p_9 K_9}{hc}\right)^{1/2} \frac{D}{E} = n \frac{D}{E} = 0.038 \frac{D}{E} \qquad (2)$$

From this equation for x we may obtain the equation

$$\frac{p_9 K_9 D_2}{E^2 x} = hcx$$

But the first member of this equation is the interest on the line conductors per kilowatt delivered, and the second member is the annual cost of the line loss per kilowatt delivered. That is, for most economical conditions the line loss per kilowatt delivered must be equal in value to the interest on the conductors per kilowatt delivered — a relation also well known.

As has already been suggested, there will be a limit to which the voltage can be carried, due to the fact that although increase of voltage will diminish the annual cost of lost power and of conductors, it will increase the annual cost of certain other important factors. The elements of annual cost which are affected by change of voltage are the interest and depreciation of the transformers, the interest on the line conductors, the line loss and the interest and depreciation of the insulators. The first and last items will increase with the voltage because of the increased first cost due to the increase of voltage; the other two will diminish.

Let q_1 = that portion of the annual cost per kilowatt of delivered power due to the line loss, conductors, insulators and transformers. It has just been shown that for best economy the line loss and annual conductor cost must be equal, so that twice the line loss, $2\,hc\,W\,x$, may be taken as representing the sum of the annual cost due to line loss and to the conductors. As will be shown later, the cost of the insulators will vary as the distance, and as the cube of the voltage and the cost of the transformers may be represented by

$$K_1' \,(E + K_1'')\, W^{1/2}$$

Hence remembering that p_1 and p_4 are the interest and depreciation on transformers and insulators, respectively,

$$q_1 = \frac{2\,hc\,W\,x + p_4 K_4 E^3 (1+x)^3 D + p_1 K_1' \,(E + K_1'')\, W^{1/2}}{W}$$

or putting in the value of $x = \left(\frac{p_9 K_9}{hc}\right)^{1/2} \frac{D}{E} = n \frac{D}{E}$

$$q_1=\frac{2\,hcn\,WDE^{-1}+p_4\,K_4\,E^3\,(1+n\,D\,E^{-1})^3\,D+p_1\,K_1'\,(E+K_1'')\,W^{1/2}}{W}$$

Now, if the first derivative of q_1 with respect to E be set equal to zero to determine the best value of E, there results a quartic equation more interesting than valuable, so far as the present purpose is concerned. It will greatly simplify matters if instead of substituting the value of x in $(1+x)^3$ we substitute for x a fixed drop (x_1) of such value as will correspond to the average cost of insulator between the two extreme values of x which will be met with in practice; as will be shown later, the error due to such course will be small. Hence,

$$q_1=\frac{2\,hcn\,WDE^{-1}+p_4\,K_4\,E^3\,(1+x_1)^3\,D+p_1\,K_1'\,(E+K_1'')\,W^{1/2}}{W}$$

Setting the first derivative of this equation equal to zero, solving for E and substituting for n the value, $n=\left(\frac{p_9\,K_9}{hc}\right)^{1/2}$, there results

$$E=\left(\frac{-p_1\,K_1'\,W^{1/2}}{6p_4\,K_4(1+x_1)^3\,D}+\sqrt{\frac{p_1^2\,K_1'^2\,W}{36\,p_4^2\,K_4^2(1+x_1)^6\,D^2}+\frac{2\,(hcp_9\,K_9)^{1/2}W}{3\,p_4\,K_4(1+x_1)^3}}\right)^{1/2}$$

$$=\left(-3{,}066\frac{W^{1/2}}{D}+\sqrt{9{,}400{,}356\frac{W}{D^2}+3{,}438.5\,W}\right)^{1/2} \qquad (3)$$

This shows that the voltage may be increased with increase of output. This was to be expected, since for a given cost of insulators the cost per kilowatt will be diminished as the output increases. The value of x_1 used in the above equation was determined upon as follows:

The minimum drop which is ever likely to obtain is, say, 2.2 per cent, the maximum, say, 11.5 per cent. The reason for selecting these values will be apparent on considering the values of E calculated from the above equation, and given below, in connection with the values of W to which they correspond, and the respective distances to which, in each case, the various amounts of power would probably be transmitted. The intermediate value of drop which will give the average insulator cost is 6.45 per cent, and this value of x_1 is taken. With this value of x_1, maximum error in insulator cost, between the limits assigned, will have place when $x=2.2$ per cent and when $x=11.5$ per cent. The percentage error at either of these limits is about 13 per cent. But, as appears in the solution of the first derivative of insulator cost, at the

point of minimum of the variables affected by the voltage, the combined values of the annual cost due to the conductors, the annual cost of the line loss, and that portion of the annual transformer cost due to voltage, is more than three times that due to the insulators. The total variable quantity involved, therefore, is more than four times the annual cost due to insulators, and the error, as a percentage of the total of values of the variables involved, is less than $\frac{13}{4} = 3.25$ per cent, instead of 13 per cent. As will be seen on examining the manner in which x_1 enters the equation for E, the maximum error in E will be less than 3 per cent, which also will to a like extent affect the values of x. These errors are negligible so far as the main problem is concerned, and, indeed, as far as the question of voltage itself is concerned.

In Fig. 1 are shown curves plotted from equation (3). These curves show the kilovolts, E; for different distances, D, and different outputs, W. Fig. 2 gives curves plotted from equation (2), using the values obtained from the curves of Fig. 1. The curves of Fig. 2 show the percentage drop, x; for different distances, D, and different outputs, W. In Fig. 3 are curves showing the diameters of the conductors for the conditions of Figs. 1 and 2. These diameters were calculated from the formula

$$d = k_5'\left(\frac{WD}{E^2 x}\right)^{1/6} = k_5'\left(\frac{WDE}{E^2 n D}\right)^{1/6} = \frac{k_5'}{n^{1/6}}\left(\frac{W}{E}\right)^{1/6} = .0219\left(\frac{W}{E}\right)^{1/6} \quad (4)$$

which gives the diameter d, in inches, of a *solid* conductor. These diameters were in this case calculated for a solid conductor instead of a stranded one, because we have at present available data as to the critical point in the atmospheric loss curve for solid conductors only, and while, perhaps, this critical point will come at a higher voltage in the case of the stranded conductor with its greater diameter, there are no definite data at present on the subject. On comparing the diameters of conductors given by Fig. 3 and the voltages to which they correspond with the values of diameters and critical voltage given by Prof. Ryan in his paper on that subject[2] we see that the diameters of Fig. 3 are considerably above those of the paper referred to. It appears, therefore, from the present knowledge available, that the limit of voltage will come through economic conditions, and not through limitations connected with atmospheric losses.

2. See paper read by Prof. Ryan before American Institute of Electrical Engineers, February 26, 1904.

In the determination of both x and E the quantity h has been employed. This quantity is a factor which when multiplied into the cost of power at the low-tension bus-bars of the step-up transformers will give the cost of power at the high-tension terminals of the transformers. That is to say, h takes account of all charges which should be made against this power, including interest and depreciation of the step-up station, transformers, etc., and labor for operating the station, also the loss in the transformers. Now, strictly, there should be substituted for h the proper functions of the quantities on which it depends, but to do so would seriously complicate the equations and would be of little utility, since h can be approximated with sufficient accuracy in any particular case, and the manner in which it occurs in both x and E is such as to make the error in the quantities due to an error in h much smaller than the error in h itself. In the specific problem herein the value $c = 10.9$ is taken as being the lowest which will probably ever obtain where large amounts of power are available within transmission distance of a desirable market. The value taken for h in the determination of E and x is 1.1, so that $hc = 12$.

The next step is the determination of the forms of the several functions indicated. In what follows, the constants have been evaluated for the specific problem herein. The costs resulting from the use of these constants will be found to be, in general, considerably less than present commercial costs. The constants were purposely based on prices less than can be now obtained in the endeavor to anticipate somewhat possible future prices.

From a careful consideration of transformer prices, it has been determined that for transformers of 1500 kw and over, the cost installed very closely follows the law

$$f_1\,(E, W) = K_1'\,(E + K_1'')\,W^{1/2} = 13.\ (E + K_1'')\,W^{1/2}$$

$$\therefore p_1 f_1\,(E, W) = p_1 K_1'\,(E + K_1'')\,W^{1/2} = 1.625.\ (E + K_1'')\,W^{1/2}$$

in which K_1' is a constant and K_1'' a "variable constant," a quantity which varies slowly with the output in accordance with the law

$$K_1'' = k_1 + k_2\,W = 55 + 0.000{,}227\ W.$$

Theoretically the transformer cost would vary with the drop x_1 since the step-up transformers would have an output and voltage greater than the step-down transformers. Practically, however, step-up and step-down transformers are built so nearly in the same lines that the drop would make little difference. Such

difference as would exist can be taken care of approximately by adjustment of the constants, which has been done.

While the apparatus for the control of the high-tension side of the transformers would theoretically vary with the voltage, such variation for 50,000 volts and over will be small, since in most modern plants the high-tension switching apparatus is simple and higher voltages are likely to cause it to remain so. The lightning protection for the high-voltage lines might vary with the voltage, but it is probable that for high voltages there will soon be a reversion to much simpler and inexpensive apparatus than we use now, so that the variation, if any, due to higher voltages will be neglible. The switchboard for the lower voltage side of the transformers will vary only with the output, since we assume the lower voltage to be the same in all cases, say 6,000 volts or thereabouts.

The apparatus for the control of transformers may therefore be considered as depending only upon output. Under this assumption a consideration of costs of transformer-controlling apparatus and cables shows that we may assume, with a close degree of accuracy, that

$$f_2\,(E, W) = K_2' + K_2''\,W = 21{,}000 + 0.9\,W$$

$$\therefore p_2 f_2\,(E, W) = p_2 K_2' + p_2 K_2''\,W = 2{,}625 + 0.1125\,W.$$

The cost of buildings and the real estate for them will increase very slowly with the output. The variation of this item, due to variation of output can be closely enough expressed by

$$f_3\,W = K_3' + K_3''\,W^{1/2} = 125{,}000 + 125\,W^{1/2}.$$

$$\therefore p_3 f_3\,W = p_3 K_3' + p_3 K_3''\,W^{1/2} = 9{,}375 + 9.375\,W^{1/2}.$$

The cost of an insulator will, theoretically, vary with the diameter of the conductor and the voltage. Practically, however, the diameter of the conductor will have nothing to do with the cost. A consideration of insulator prices shows that the cost of an insulator will vary as the sum of a small constant plus the product of a constant into the cube of the voltage. With high voltages the small constant is negligible, so that we may write

$$f_4\,(E,d,D) = K_4\,E^3 (1 + x_1)^3\,D = 0.000{,}732\ (1.0645)^3\,E^3\,D = 0.000{,}883\,E^3\,D \therefore p_4 f_4\,(E, d, D) = p_4 K_4 E^3\,(1 + x_1)^3\,D = 0.000.088{,}3\,E^3\,D.$$

The cost of the pole-line material and construction will depend somewhat upon the diameters of the conductors, since as the diameters of the conductors increase, the wind and sleet stresses will increase. The increase of cost with increase in diameters of con-

ductors will be slow. The law followed will be that of a constant plus a function of the diameters of conductors, since no matter how small the diameters of conductors there will be a certain cost representing the minimum size pole which would be employed. We may, with a fair degree of accuracy, write

$$f_5(d,D)=(K_5'+K_5''\,d)D=f_5(E,W,x,D)=K_5'D+K_5''k_5\left(\frac{WD}{E^2x}\right)^{1/2}D$$

or putting in the value of $x=n\dfrac{D}{E}$

$$f_5(E,W,x,D)=K_5'D+\frac{K_5''\,k_5}{n^{1/2}}\left(\frac{W}{E}\right)^{1/2}D=3{,}000\,D+37.2\left(\frac{W}{E}\right)^{1/2}D$$

$$\therefore p_5f_5(E,W,x,D)=p_5K_5'D+\frac{p_5K_5''k_5}{n^{1/2}}\left(\frac{W}{E}\right)^{1/2}D=375\,D+4.65\left(\frac{W}{E}\right)^{1/2}D$$

which answers for a stranded conductor.

Cost of right of way will be directly proportional to distance, hence

$$f_6\,(D)=K_6\,D=1000\,D.$$
$$\therefore p_6\,f_6\,(D)=p_6\,K_6\,D=50\,D.$$

A consideration of synchronous motor prices shows that the cost of synchronous motors may be written

$$f_7\;(W)=K_7'+K_7''\,W=12{,}000+32.4\,W.$$
$$\therefore p_7\,f_7\,(W)=p_7\,K_7'+p_7\,K_7''\,W=1{,}500+4.05\,W.$$

The switchboards and cables for the motors will follow the same law as those for the transformers, hence

$$f_8\,(W)=K_8'+K_8''\,W=8{,}400+0.17\,W.$$
$$\therefore p_8\,f_8\;(W)\;=p_8\,K_8'+p_8\,K_8''\;W=1{,}050+0.021{,}25\,W.$$

From the well-known relations between the cost of conductors and the voltage, distance, output and drop, we may write

$$f_9\,(E,\;W,\,x,\,D)\;=\;K_9\,\frac{W\,D^2}{E^2\,x}=0.346\frac{W\,D^2}{E^2x}$$

or putting in the value of $x=n\,\dfrac{D}{E}$

$$f_9\,(E,\;W,\,x,\,D)\;=\;K_9\,\frac{WD}{E\,n}=\frac{K_9}{n}\,\frac{W\,D}{E}=9.1\,\frac{W\,D}{E}$$

$$\therefore p_9\,f_9\,(E,\;W,\,x,\,D)=p_9\frac{K_9}{n}\frac{W\,D}{E}=0.455\,\frac{W\,D}{E}$$

The cost of labor for the operation of the step-up and step-down transformer stations and for executive and clerical purposes would probably not vary at all. We have in each case the same number of units to be looked after and the size of these units would make little, if any, difference in the cost of attendance upon them. Similarly, the output will make little difference in executive and clerical costs. We would probably be justified in making $f_{10}\ (W)$ a constant. In order, however, to cover such small increase in labor and salaries as there might be with increase of output we will write

$$f_{10}\ (W) = K_{10}' + K_{10}''\ W^{1/2} = 32{,}000 + 26\ W^{1/2}.$$

It is to be noted that the labor in connection with the line is taken care of in the depreciation and repair percentages applicable to the supporting structure and insulators respectively.

The efficiency of the whole system is $\dfrac{e_1}{1+x}$ (see page 473).

Putting in the value of $x = n\dfrac{D}{E}$

$$e = \frac{e_1}{1 + n\dfrac{D}{E}} = \frac{0.925}{1 + 0.038\dfrac{D}{E}}$$

$$\frac{Wc}{e} = \frac{W\left(1 + n\dfrac{D}{E}\right)c}{e_1} = \frac{Wc}{e_1} + \frac{nc}{e_1}\cdot\frac{WD}{E} = 11.78\ W + 0.448\frac{WD}{E}.$$

The various functions above arrived at may now be utilized in obtaining N and M of equation (1) $p = \dfrac{N}{M}\cdot$

Remembering that R is the sum of the products of the various functions by the corresponding percentages representing interest, depreciation and repair; that $L = f_{10}\ (W)$; and representing the various resulting collections of constant as follows:

$$a = p_2\ K_2'' + p_7\ K_7'' + p_8\ K_8'' = 4.184.$$

$$b = K_{10}' + p_2\ K_2' + p_3\ K_3' + p_7\ K_7' + p_8\ K_8' = 46{,}550.$$

$$m = K_{10}'' + p_3\ K_3'' = 35.38.$$

$$r = p_5\ K_5'' + p_6\ K_6 = 425.$$

then $N = Ws - \dfrac{Wc\ (1+x)}{e_1} - L - R =$

$$\left(s - \frac{c}{e_1} - a\right) W - \left(\frac{nc}{e_1} + \frac{p_9\ K_9}{n}\right)\frac{WD}{E} - m\,W^{1/2} - p_1 K_1'(E + K_1'')\,W^{1/2}$$

$$- p_4 K_4 (1 + x_1)^3 E^3 D - rD - \frac{p_5\ K_5''\ k_5}{n^{1/2}}\left(\frac{W^{1/2}}{D}\right) D - b.$$

Representing constants as follows:

$$\alpha = K_2'' + K_7'' + K_8'' = 33.47.$$

$$\beta = K_2' + K_3' + K_7' + K_8' = 166{,}400.$$

$$\gamma = K_5' + K_6 = 4{,}000.$$

Then

$$M = \alpha W + \frac{K_9 WD}{n E} + K_3'' W^{1/2} + K_1' (E + K_1'') W^{1/2} + K_4^{\cdot} (1+x_1)^3 E^3 D + \gamma D + \frac{K_5'' k_5}{n^{1/2}} \left(\frac{W}{E}\right)^{1/2} D + \beta.$$

These values of N and M, if substituted in equation (1), will give in its final form the equation connecting distance, output, voltage and profit; or in connection with equation (3) for voltage, the relation between distance, output and profit. Such substitution results in a cumbersome equation, and will not be here written. If the various numerical values already determined for the specific problem herein treated be substituted in N and M there results

$$N = (s - 15.96)\, W - 0.903 \frac{WD}{E} - 35.38\, W^{1/2} - 1.625\, (E + K_1'')\, W^{1/2} - 0.000{,}088{,}3\, E^3 D - 425\, D - 4.65 \left(\frac{W}{E}\right)^{1/2} D - 46{,}550.$$

$$M = 33.47\, W + 9.1 \frac{WD}{E} + 125\, W^{1/2} + 13\, (E + K_1'')\, W^{1/2} + 0.000{,}883\, E^3 D + 4{,}000\, D + 37.2 \left(\frac{W}{E}\right)^{1/2} D + 166{,}400.$$

The value of s in the above equation for N will be taken as 34; that is, it will be assumed, for the purposes of the specific problem, that power is sold at \$34 per kw year. Putting in this value of s and calculating the value of p for different outputs, W, and different distances, D, the curves of Fig. 4 have been obtained. These curves show for different values of W the relation between p and D.

In considering these curves the assumption made in connection with them should be carefully borne in mind. A small change in the purchase price or selling price of power will make a great difference in the result. Smaller amounts of power will in general be purchased at a higher price per kilowatt, but on the other hand they would probably be transmitted to points where the power would bring a higher price, since, in general, the larger the market the cheaper can power be produced by steam.

It would be interesting to let $s - c/e_1$ equal to zero and determine

p, which would then be the cost, including interest, of operating the plant. If curves showing the percentage of the investment for operation were determined, also the total cost of the plant, both for different outputs, the results would be valuable in preliminary estimates. The writer hopes to work up such data at a later date.

It will be noticed on referring to the curves that some of them reach to distances which cause the drop to exceed the value taken for the upper limit of drop in connection with insulator cost. The error due to 1 or 2 per cent excess will not greatly affect the final result. It would have been somewhat better, however, for the specific problem treated to have chosen the limits of drop as 5 per cent and 15 per cent respectively instead of those taken.

TRANSACTIONS

OF

SECTION E

Electric Light and Distribution

Honorary Chairman, SENOR MIGUEL OTAMENDI
Chairman, MR. JNO. W. LIEB, JR.
Vice President, DR. JORGE NEWBERY
Secretary, MR. GANO S. DUNN
Assistant Secretary, MR. G. FACCIOLI

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Section E was called to order at 11:15 a. m., Monday, September 12, 1904, Chairman J. W. Lieb, Jr., presiding.

Chairman Lieb: It gives me pleasure to invite the official representatives of the National Electric Light Association and the Association of Edison Illuminating Companies to be joint chairmen in this Section during the session at which papers are to be read by representatives of these bodies. I have the honor to extend to the Honorary Chairman and Vice-Presidents of this Section an invitation to occupy the chair jointly with the Chairman of this Section. We will first take up the paper by Mr. Arthur Wright, which Mr. J. R. Dick has kindly consented to read. This will be followed by the paper of Mr. E. De Fodor, to be read by Mr. Philip Torchio. The two papers will then be discussed jointly.

Mr. J. R. Dick then read the paper by Mr. Arthur Wright, which follows:

SOME RECENT IMPROVEMENT IN ELECTROLYTIC METERS.

BY ARTHUR WRIGHT.

From a careful study of the conditions governing the consumption of electricity in a large town having over 4000 consumers, the author has been convinced that it is just as essential to the profitability of an electric supply business for electric meters to correctly and economically register the electricity consumed at light loads, as it is that they should do so at full loads; and realizing the shortcomings of many of the meters on the market in this respect, particularly after they have been in service for a few months, he is anxious to bring before the members of this important Congress a type of electric meter, which in the author's opinion is free from this serious charge of under-registration and heavy consumption of energy at light loads.

Before describing the apparatus in question, the author thinks the following considerations will justify some attention being given to the question of improvement in electricity meters.

The meter department of an electric supply business, considering its vast importance on the net profits, frequently does not receive the attention it deserves from the central station manager. When it is realized that as much money is now often wasted by the use of imperfect meters as can be lost by the use of inefficient engines and boilers for electricity-supply undertakings, the seriousness of the neglect of the meter department becomes very tangible. Doubtless owing to the fact that meters are, of necessity, out of the sight of managers of central stations, and that they usually give so little trouble either to the managers or to the consumers, this end of the electricity business receives far less serious study than have the boiler-house and engine-room equipments, although about the same amount of capital is usually absorbed by these two departments. Nevertheless, it can be easily proved that in the meter department, the cost of the energy consumed in the shunt winding of the ordinary meters, the loss of revenue due to the

under-registration at light loads; and the cost of motor-meter repairs will generally amount to more than 7 per cent of the total income, which, as above stated, is probably more than the ordinary loss in an electric-lighting business through the use of inefficient steam engines and boilers. It is worth while noting here that this waste caused by the use of imperfect meters, if saved, would be sufficient to pay about 2 per cent annually more on the total investment, and that this improvement in return in many cases would make all the difference between the ability or the reverse, of obtaining further capital for the extension of the business. The correct registration of meters at half and full load has long been possible, and is generally insisted upon; but it is only lately that the equal importance of correct light-load registration has become recognized.

To illustrate the small attention most of the central station men have given to this question of correct registration at light load, the author has only to remind the members that a very usual method of ascertaining whether a meter is correctly working after it has been once tested and installed on a consumer's premises is to see if it will start rotating when only one lamp is switched on. Generally, if a meter moves at all under this load it is considered to be good enough to remain, notwithstanding that no information at all has been thereby obtained as to its correct registration at any load. It is, of course, obvious that with such rough methods of testing, central station men can have no idea of the loss of revenue that is occasioned to their undertaking by the continued use of under-registering meters. In fact, some of us have been in the habit of making meters slightly over-register at full load with the impression that this will be sufficient to correct under-registration at light load. It must be remembered that from the very nature of most motor-meters, the tendency must be for them to more and more under-register at light loads as the time of service increases, owing to the gradual increase in the friction of the meters' pivots or of that between the commutator and its brushes.

The following sequence of considerations will probably show that it is just as important to a supply company for meters to register accurately below half-load as at full load.

1). It is usual to install meters, the full-load capacity of which is greater than the total number of lamps in the installation.

2). The maximum number of lamps simultaneously alight in an installation is generally less than the total number installed.

3). The average load on the meter is considerably less than the maximum load.

4). During the greater number of those hours in the year during which some electricity is required, the actual load is much less than the average load. In other words, meters are more frequently worked at light load than at full load, and moreover, light loads are generally on for many more hours at a time than are heavy loads. This can easily be demonstrated by plotting out the annual load curve of any average private residence, from which it will be seen that certainly more than half the annual consumption in kilowatt-hours is taken at less than half the maximum load of the year. Some engineers have been heard to say that the well-known loss of revenue due to the under-registration of meters at light loads is a very convenient form of lowering the price of electricity during the time the generating station is underloaded, and a tariff and a meter has actually been proposed having this argument as their basis. In the author's opinion, this method of reasoning indicates a very slack method of doing business, as the reduction in the consumer's bill thereby obtained is given in a form for which the public will never give the supply company any credit. The probable reason why central station men continue to use meters which needlessly waste about 7 per cent of their income is either that they do not recognize that more than half the revenue of their business is derived under conditions during which the meters are working at less than half-load, or that they are not aware of the possibility of obtaining satisfactory meters which can register accurately over a hundred-fold range after one or two years' continuous use.

The author would like to remark here that many inventors have realized the importance of correct registration of meters at light loads, and this object has been the cause of some of the most beautiful inventions in electrical instrument making. Witness for example the compound winding adopted by Ferranti and Elihu Thomson, the beautiful magnetic suspension of Mr. Stanley, the varying friction correcting devices of M. Brillé and Mr. Evershed. As all of these forms of correction for friction are apt to vary in efficiency as time goes on, from mechanical reasons, the permanency of the hoped-for cure can never be assured.

Leaving now the importance of correct registration at light loads, the author desires to remind the members that an almost

equally serious loss is occasioned by the use of the shunt winding of most motor-meters and that the capitalized cost of the energy consumed in the shunt circuit of the ordinary watt-hour meter is over $10.50 when used on 100-volt circuits, and $21 when used on the 250-volt circuits now likely to become more and more common. As a matter of fact, the loss of energy in the meter shunt on 250-volt systems can easily amount to 10 per cent of the total output in kilowatt-hours.

From the above considerations the author felt that, given a reliable system of supply, next to the importance of studying the correct system of charging for electrical energy, came this question of improvement in electricity meters, and as he and his colleagues, the Reason Manufacturing Company, after working for years on this subject, have, he believes, succeeded in producing a perfectly accurate meter which can be sold at a lower price than any motor-meter on the market, he feels that he is justified in introducing the subject to the members of this important Congress, notwithstanding the risk he thereby runs of appearing to present merely an elaborate form of advertisement for some recent work he is interested in. The author trusts, however, that when some of the effects to be described are studied, and the many interesting possible applications to commercial electricity are realized, the members will overlook some of his enthusiasm on the subject of a meter based on the electrolysis of mercury.

To arrest the attention of those central station managers who are under the impression that all electrolytic meters are messy, wet things which very much under-register at light loads, are expensive to maintain, and unsuitable for making watt-hour measurements or for the measurements of alternating currents, the features of the mercury electrolytic meter he is about to describe can be enumerated as follows:

1). It consists in its simplest form of a hermetically sealed meter, self-contained, clean, and as durable as an ordinary thermometer, and almost equally simple in construction, capable of registering at all loads from 1000th to full load with a maximum loss at full load of half a volt.

2). An apparatus without any moving mechanical parts or anything likely to wear out or vary.

3). A type of accurate meter whose maintenance cost is nil.

4). A meter capable of being made in a perfectly portable form suitable for use on trolley cars and automobiles.

5). A meter which, if desired, can be made to register watt-hours instead of ampere-hours by the addition of a special shunt solenoid mechanism.

6). An electrolytic meter which is capable of being used to measure accurately alternating currents by the addition of a simple form of transformer.

7). An unalterable meter which must, by its very simplicity, cost much less to make than any commercial motor-meter on the market.

8). A type of meter of which about 16,000 are now in use notwithstanding it has been barely two and a half years out of the experimental stage.

The apparatus which the author desires to bring to the notice of the members consists in its simplest and latest form of a small egg-shaped glass bulb horizontally divided into two compartments by a diaphragm of fine platinum gauze. This diaphragm is shaped like a cone and has a small aperture at its apex which is pointed upwards. Close beneath the base of this gauze cone, a ring of platinum foil is supported, the surface of which has been coated with platinum black to prevent the adherence of the mercury that is deposited on it when in action. At the bottom end of the glass bulb an index tube of elliptical section is attached with its accompanying scale having divisions approximately 1 mm apart. Before sealing up the glass bulb, sufficient pure mercury is poured on to the top of the gauze diaphragm to a depth of about a quarter of an inch or to about half the height of the cone; the remainder of the apparatus is then filled with a slightly acid solution of mercurous nitrate. By means of platinum leading-in wires the gauze diaphragm is made the anode, and the platinized ring underneath, the cathode of the electrolytic cell. The amount of mercury and the index tube's length are generally made sufficient for 250 hours' use at full load. The glass apparatus, its attached scale, and the connecting wires are preferably supported by a system of springs in a protecting iron case, and a portion of the main current to be measured is derived from a large platinoid wire shunt, and passes through a copper resistance coil on its way to the electrolytic cell. In use, after most of the mercury has been transferred by electrolysis from above the anode gauze diaphragm to the cathode ring beneath and thence to the index tube, the meter is reset by hand by merely tilting the tube upward on the hinges, so that the mercury that has collected in the index tube passes through the hole

in the cone's apex back to the anode chamber, where the capillary repulsion of the platinum gauze supports the metallic mercury, without interfering with both the bottom and top surfaces of the mercury, being exposed to the full action of the electrolyte. When

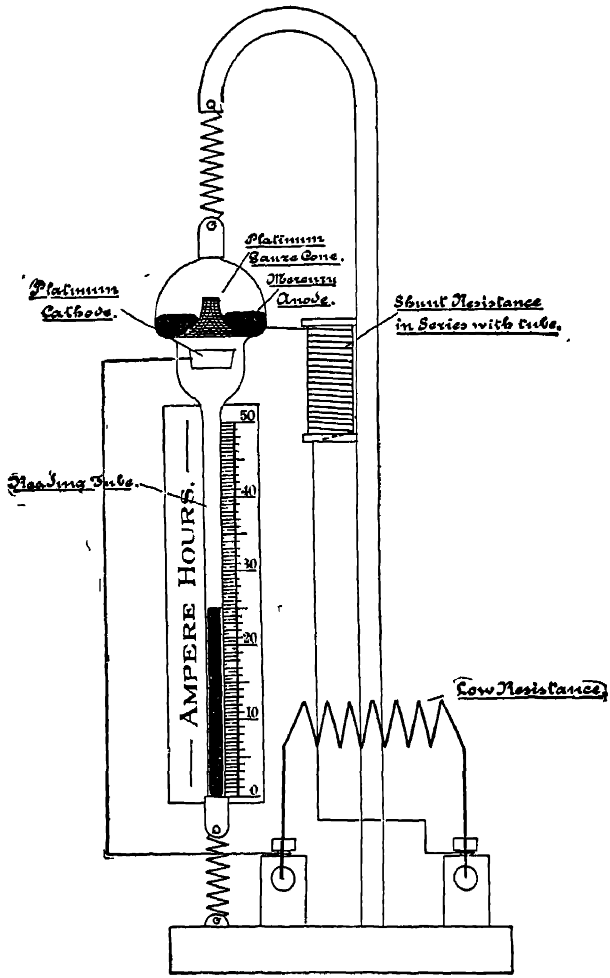


FIG. 1.

it is undesirable to reset the meters more frequently than once a year, the time range of the above instrument can be extended by the use of the syphon-shaped index tube which, on becoming full of mercury, automatically empties itself into a larger index tube

below; the extra quantity of mercury required for this type is automatically fed to the anode compartment from an attached reservoir after the manner of a bird-fountain.

When it is necessary to measure watt-hours instead of ampere-hours, the electrolytic cell is connected across a main current shunt, whose resistance is made to vary in proportion to the variation of the voltage circuit to be measured, and as in practice more than a 10-per-cent variation of pressure is rare, only 10 per cent of the total main resistance need be made variable in this manner.

The above mercury electrolytic meter, as is usually the case with most inventions, has had many ancestors, the most important of which, as far as the author has been able to trace, are as follows:

1). The original mercury electrolytic meter devised by Mr. Varley in the year 1883, consisting of a porous cell filled with mercury constituting the cathode; this was placed in a containing jar having a mass of mercury at the bottom acting as the anode, the intention being to make the cathode mercury to overflow by electrolysis into a measuring tube or back into the cathode mercury, and

2). Messrs. McKenna and Anders' types of the year 1892, in which the cathode consisting either of a graphite rod or platinum surface was placed above the mercury anode, the deposited mercury from the cathode in both cases being made to drop into an index tube below the anode. All these types must have been defective by reason of the cathode being placed above the anode, as the stagnation of the electrolyte necessarily caused the mercury anode to become covered and insulated by a layer of crystals, thus preventing further electrolysis. It was doubtless owing to the mechanical difficulty of placing the cathode below the anode, while at the same time insuring that the surfaces of the anode should be bathed in a constantly moving electrolyte, and of making a type in which the mercury of the anode was not easily upset, that so little was apparently done in the way of mercury electrolytic meters.

As is now well known, all the older forms of electrolytic meters having metallic anodes, when working in parallel with a metallic main current shunt, suffered from the fault of under-registration at light loads, due to an appreciable counter e.m.f. consequent on the unequal concentration of the electrolyte. In 1899 the author found that this serious defect could be completely corrected by

means of adding a very small constant e.m.f. to the electrolytic cell's circuit, either by an actual voltaic cell or by the equivalent addition obtained by shunting a portion of a high resistance connected across the two poles of the circuit to be measured. He thereupon applied this method of correction to the simplest complete electrolytic meter that has been devised, viz., the Grassot meter, which is dependent for its action on the gradual eating away of the end of a metal rod, which forms at the same time the anode of the cell and the indicator, against a scale, of the number of ampere-hours consumed. The application of the above corrector enabled the author to make a cheap, perfectly accurate, and easily-read meter, but it was still messy and uncommercial, owing to the salts gradually creeping up the walls of the container and the necessity existing of having to renew the anode rods. The author then applied this correction principle to the Varley mercury electrolytic meter with fairly good results. Owing, however, to the principle involved requiring the cathode to be always higher than the anode, this form was unsatisfactory for other than very short duration measurements, as the surface of the anode rapidly becomes covered with crystals of mercurous nitrate through the entire absence of any circulation in the electrolyte. Notwithstanding this difficulty with mercury, the author found, upon taking a series of tests, that if the stagnation of the electrolyte could be overcome, a mercury electrolytic meter could be made to register accurately at all loads when shunted by a metallic resistance. It was not easy at first to devise a form to overcome the physical difficulty of constructing a portable meter having a mercury anode placed above the cathode, and at the same time having most of the surface of the anode exposed to the action of the electrolyte. Ultimately, after many devices having been tried with more or less satisfactory results, a simple solution was found in the use of a platinum wire gauze anode mercury container; this completely solved the difficulty in that it enabled a large surface of mercury to be exposed near the top of the electrolyte in very close proximity to the cathode placed below it, thus enabling the heavy mercurous solution resulting from the electrolysis to fall by gravity directly on to the cathode, and at the same time permit the lighter impoverished liquid to rise from the cathode up to the anode surface in a way which is naturally adopted in all electrolytic cells having solid anodes.

Another reason, besides the difficulty of placing the cathode under the anode, why workers have failed to secure satisfactory results with mercury electrolytic meters, was probably the necessity of having to use extremely pure chemicals, and the present

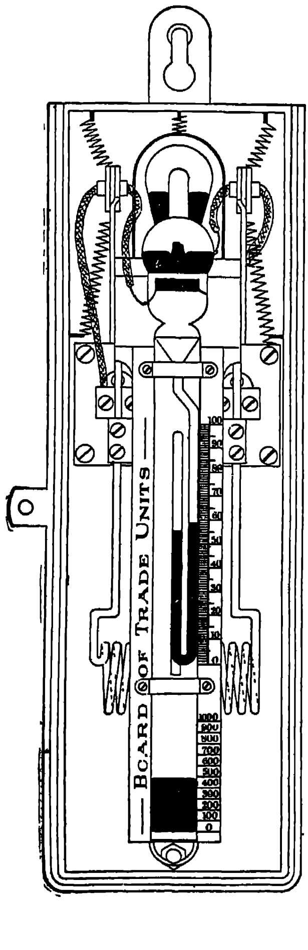


FIG. 2.

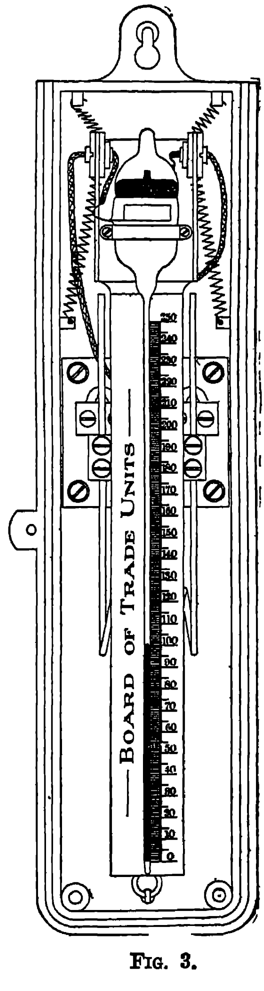


FIG. 3.

manufacturers of the meters in England have only succeeded through their thorough mastery of the science of chemical cleanliness and purity, and their skill in devising the many mechanical items requisite for the commercial development of the ideas out-

lined above. It must be obvious that in the mercury electrolytic meter the law of registration at any load must be purely a fixed physical one and not one constantly varying from causes such as friction which motor-meters are always subject to. It has been found from experiment that if the electrolyte contains a portion of $1\frac{1}{4}$ per cent of free nitric acid, its composition will remain always the same, consequently the internal resistance of the meter remains constant when the Edison temperature-correcting device is used in conjunction with it. Owing to the mercurous nitrate solution being incapable of freezing unless the temperature is less than 25 deg. F., there is little reason to fear trouble in practice from the freezing of the electrolyte; should it, however, become necessary to expose meters to situations which are subject to lower temperatures than the above, the freezing difficulty can be entirely obviated by adopting Mr. Edison's thermostatic lamp device.

The stagnation of the electrolyte having thus been overcome and the absence of the polarization error at light loads having been proved, it was merely a matter of chemical and mechanical skill to perfect the details, such as the exact chemical solution to insure the permanency of the internal resistance, the proper method of suspension, and the best means for obtaining long range as regards time.

In order to test the meter's accuracy at all loads, tests were made of the polarization e.m.f. at different loads, with the results showing that with a meter having a maximum drop of a quarter of a volt at full load, the accuracy of registration in accordance with Faraday's law would be as follows:

At half-load, 98.6 per cent; at quarter-load, 97.7 per cent; at 10th load, 97 per cent; at 50th load, 96.1 per cent; at 100th load, 95.7 per cent; at 200th full load, 94.2 per cent.

If the maximum drop at full load be allowed to be one volt, the percentage of accuracy at 1000th of full load will be 94 per cent.

The following advantages accrue from the use of meters having this extremely long range of accurate registration:

1). Increased revenue compared to that derived from ordinary motor-meters.

2). The possibility of having to keep a much smaller meter stock owing to only one size of meters (say of 20 or 30 ampere maximum capacity) being required for probably over 90 per cent of the consumers, instead of having to keep a large assorted stock of meters of $2\frac{1}{2}$, 5, 10, and 20 ampere capacity, respectively.

3). The advantage of being able to make the chief part of the apparatus — the electrolytic cell — exactly the same for practically all the sizes of meters required in practice.

To confirm this greater accuracy of registration of the mercury meter at all loads over the usual types of motor-meters used in Europe, the author had electrolytic meters placed in series with motor-meters on a large number of consumers' premises, taken at random, and found that the electrolytic meters registered on the average 8.6 per cent greater consumption than the motor-meters. The author thinks it well to point out that this difference if capitalized on a ten-years' basis is more than sufficient to pay for the entire scrapping of the old meters. It is hardly necessary to point out to the members that the mercury-meter scale, like that of a thermometer, is capable of being more accurately read than the dial of the ordinary gas or motor electric meter.

By a very careful series of tests it was determined that the opposing e.m.f. of polarization in a meter having a fall of potential of only a quarter of a volt at full load was as follows:

At 100th full load, .000,18 of a volt; at 50th full load, .000,345 of a volt; at 10th full load, .001,5 of a volt.

These exceedingly small values of the opposing e.m.f. hardly prepared the author for the remarkable property this gauze type of mercury electrolytic meter possessed of rectifying alternating currents when used in conjunction with a shunt of comparatively low resistance, and its consequent property of enabling such a type to be used for alternating-current measurements. As the above property is not a true case of electrolysis by alternating currents, or of an action analogous to the well-known property of an aluminum anode, the author has not at present made up his mind as to what is the true explanation of this useful effect; but he has, in the meantime, determined that by a very slight modification of the meter's shunt circuits an accurate electrolytic alternating meter can be obtained.

Chairman Lieb: If Mr. Torchio will be kind enough to read Mr. De Fodor's paper, we will proceed with that before entering upon a discussion of Mr. Wright's paper. I will ask both Mr. Dick and Mr. Torchio to make some notes when we come to the discussion of the papers, so that they may be able to answer any questions which may arise, and that will facilitate the discussion.

Mr. Torchio then read Mr. De Fodor's paper, as follows:

RATES FOR ELECTRICITY SUPPLY.

BY ETIENNE DE FODOR.

If we take a retrospective glance in the history of current tariffs, we will find that at the beginning the endeavors were to make such tariffs as simple as possible. However, with the lapse of time, it became necessary to sacrifice such simplicity and establish rates in various grades as circumstances and local conditions demanded. It may seem astonishing to assert that at present there exist nearly as many rates as there are central stations; yet in fact this is true and can be confirmed.

In most cases — at least the larger — electrical central stations were erected in opposition to existing gas companies, which had acquired through many years a vast amount of experience in the art of lighting and power distribution. So long as they relied upon the old flame burner, the gás companies at that time had nothing to bring in opposition to the brilliant and steady light of the electric arc, and it seemed at the time that the electric light would entirely supersede gas. It was evident that the moment competition arose between the existing gas companies and the new undertakings, the latter would be forced to adapt itself to the local conditions prevailing. The desire to win over this or that consumer from the gas companies rendered it necessary for the electric companies to make changes from any contemplated high standard rate, and one can therefore say, that in the history of every electrical current tariff there was a period in which the tariff could be designated as a war tariff.

This peculiarity of tariffs was specially prominent in current charges on account of its division in two parts, namely, one for light and one for power. It is known that from the beginning in the delivery of electrical energy an attempt was made to conform to such usages and conditions as existed at the time with respect to gas. The 8 and 16 candle power units that we still retain are a heritage from the gas companies. In the creation of separate tariffs for light and power by the first electrical central stations,

the practice of gas companies was followed, which method of charging, it may be mentioned, had just been introduced by the latter concerns with considerable misgivings. When toward the end of 1879, Thomas A. Edison announced to the world that he had solved the problem of electric light subdivision, and owing to growing competition from cheap petroleum, gas companies began to exert themselves and concentrated their attention to the utilization of gas for power purposes. It was at this period, just before the day of electrical central stations, that the two-rate gas tariff system came into operation. It was thus upon the basis of this two-rate system that the gas companies conducted their opposition against the electric light, while on the other hand, the electric companies quickly took up and employed the same means to fight the gas companies.

However, electrical central stations were forced from the beginning to make an enormous difference in price between current for light and current for power, while with the gas companies this difference was at first only 10 to 20% and later on in few cases barely reached 40%. Since that time the gas companies have had ample opportunities to recover from the shock which the Edison invention gave them, and after the invention and perfection of the Auer-Welsbach mantle, they have been placed in a position which enables them to face almost indifferently the formerly feared opposition of the electric light. Through systematic effort they have succeeded in extending the use of gas to heating purposes, thus establishing themselves in a position free of hazard concerning the profitable conduct of gas companies for a long time in the future. These and other vital advantages which gas companies possess, have made it possible for them to discard war tariffs with respect to central stations, and slowly to return to the unit prices which they evolved about a quarter of a century ago.

That the gas companies have understood and succeeded in finding new and profitable markets for their products, is proven by the fact that the quantity of gas consumed for so-called "industrial" purposes — that is, for power and heating — is a relatively large percentage of the total amount generated. Last year this percentage amounted in Darmstadt to 46.76%; Munich to 46.60%; Düsseldorf to 43.02%; Hildesheim to 39.27%; Elberfeld to 39.20%; Cologne to 35.49%; Oldenburg to 34.97% of the total gas amount generated. This considerable increase in gas supplied for industrial purposes also implies an increase in the public

demand for cheap gas, whereas rates for lighting purposes, which is the more profitable branch, have not had the same rising tendency. The gas companies, seeing that the public were daily becoming more familiarized with the use of gas for industrial purposes, soon became convinced that an eventual increase in the price of "industrial" gas would not be followed by any decrease in its consumption or demand. At the same time it was clear to them that an eventual decrease in the price of gas for lighting purposes would result in a rapid increase and demand. The largest gas company in Germany, the Berlin Gas Company, asked in 1900, 16 pfennigs for a cubic metre of gas for lighting purposes, while the charge for industrial purposes was only 10 pfennigs, or a difference of 37%. The Berlin Gas Co. for the above-mentioned reasons decided to drop this two-rate tariff and replace it by a unit price of 12 pfennigs regardless of the purpose for which the gas was used. This unit price was introduced April 1, 1901. The price of industrial gas was thus raised from that date by 2 pfennigs or 20%, whereas the price of gas for lighting was decreased by 4 pfennigs or 25%. The gas people thought this at first a very risky operation, and they calculated that in the first year there would be a falling out in the receipts of the company to the amount of about 3,000,000 marks. These fears however proved unfounded, as it was soon seen that there was no decrease in the receipts or in consumption. On the contrary, the second year after the introduction of the unit price, the former regular yearly increase in gas consumption, which amounted to 6.2%, went up to 9.7% for the central part of Berlin, while for the suburban districts it reached 15.2%. Such glaring facts should indicate the path which electric central stations should follow, and should tend to put an end, on the one hand, to the irrational practice in lowering beyond bounds the price for power current, and on the other hand, lead to a lower unit price for lighting current, thus increasing the receipts and profits of electrical stations.

While at present there exists a tendency on the part of the gas companies to give up the old two-rate system and come back to a single unit price or tariff, we find that in the most cases the tendency of electrical managers is on the contrary and most unfortunately toward granting the broadest concessions for power current, notwithstanding the wide gap already existing between lighting and power prices. Nevertheless the lowering of rates for power current seems apparently to have been attended with gratify-

ing results. In Berlin, for instance, from 1902 to 1903 there was a diminution in the number of gas motors amounting to 87, aggregating 312 H. P. In Munich during the same year the decrease in the consumption of power gas amounted to 18.68% under the preceding year, while the decrease in the number of gas motors amounted to 34, representing 157 H. P. In Berne during the same year the decrease in motor gas amounted to 35.6%.

There were, however, other gas companies — for example, those in Cologne, Kaiserslautern and Bonn — which, notwithstanding sharp competition of electric motors, showed an increase in the consumption of power gas as well in the number of gas motors. As a striking example, the gas company in Cologne increased the number of gas motors from 675, representing 3,382 H. P., to 712, aggregating 3,482 H. P. It is most remarkable to note that this increase took place only in motors of small capacity, from 3 to 5 H. P., so one could assume that the competition of gas against electric motors might only be feared from engines of larger capacity, say from 10 to 50 H. P. The falling off of gas motors in Munich was caused by the high price paid there for power gas, which cost 17.5 pfennigs per cubic metre with no discounts allowed, while the kilowatt-hour for electrical energy cost 20 pfennigs only, on which low price there was besides a discount varying according to the quantity and the time at which current is taken. It was therefore the high price of gas that caused the decrease in Munich, where the hp-hour developed by gas motors cost 77.68 pfennigs, while that for electric motors was only 62.49 pfennigs. In Berlin the decrease in gas motors is not due entirely to an increased demand for electric motors of small dimensions up to 6 H. P., but to the fact that new competition has arisen in the form of Dowson gas, petroleum and benzine motors and the like.

The set-back of the gas motor has not been due to the fact that electric motor service is somewhat cheaper than other forms of power. Good coal gas motors of small dimensions require about 575 litres of gas per hp-hour, while larger engines consume only 500 litres. Taking therefore the Berlin unit price of coal gas at 12 pfennigs per cubic metre, we can obtain a hp-hour from gas engines at 6.9 pfennigs; if the electric motor were to compete with the gas motor upon the basis of equivalent cost, it would be necessary for the Berlin Central Station to decrease its rate per kw-hour to 8.4 pfennigs, the present price for motor current being 16 pfennigs, which approaches the lowest allowable limit; and this ex-

tremely low price is just about double what is necessary to compete against the gas motor rate.

If there is an increasing demand for electric motors notwithstanding the fact that this form of energy costs double, and in many cases much more than double the cost of other forms of energy, it will be found that the reason lies principally in the specific advantages the electric motor possesses, such as simplicity of service, noiselessness, cleanliness, the small space required, etc. Where the daily cost of energy is considered the main factor, the electric motor will be kept out by the gas engine, and this latter in turn by generator gas or the benzine motor. On the other hand, where space and the admirable flexibility of the system are the principal considerations, and the daily cost of energy is but a secondary factor, the electric motor will always hold its position, even when the cost is considerably higher than it now is in general.

If we desire therefore to standardize our tariffs for current, we must above all stop at opposition tariffs against gas. If the electric light and motor cannot maintain their position through the many advantages they both possess, they surely cannot prevail in competition with gas companies. For the present, at least, it is extremely difficult to compete against the gas motor or Auer-Welsbach mantle in cheapness. Our stronghold is in the many specific advantages that the electrical form of energy possess. These advantages make it therefore wholly unnecessary to jeopardize the incomes of electric light and power companies through indulging in extravagant decreases in the price for power current.

It cannot be disputed that at the beginning it was necessary for electrical central stations to offer certain inducements in the form of cheap or reduced rates for power current, in order to effect a popular introduction of the electric motor and make its advantages known. It was also the fashion at the time to patronize the development of home and small industries, and central stations in granting a cheap power current rate, assisted in a certain sense in the solution of a problem in social economy. It was also thought that cheap motor current would be the means of introducing electricity among the poorer classes, where in the form of light it would never have had a chance. Notwithstanding all these facts, it was never necessary to make such a huge difference between the price of light and power current as is shown in the following table, which gives the unit prices per kw-hour of fifty central stations.

UNIT PRICES OF ELECTRICAL ENERGY IN PFENNIGS.

	For light.	For power.
Berlin	55	16
Vienna (Internationale)	66	40
Mexico	80	24
Frankfort, à. M.	60	20
Hamburg	60	20
Munich	60	20
Strassburg, i. E.	50	20
Copenhagen	56	17
Mannheim	60	20
Budapest	66	40
Stuttgart	60	20
Nürnberg	70	20
Dresden	60	25
Dortmund	40	20
Stockholm	56	22
Christiania	56	22
Cologne	70	25
Hannover	60	20
Magdeburg	60	20
Leipzig	70	20
Düsseldorf	70	20
Breslau	68	20
Plauen, i. V.	70	20
Stettin	60	40
Deuben	40	14
Zürich	64	24
Mähr. Ostrau	54	23
Bremen	72	24
Wiesbaden	70	15
Elberfeld	60	20
Aix-la-Chapelle	70	18
Rotterdam	60	42
Pforzheim	70	25
Bitterfeld	60	16
Brühl	50	18
Pirmasens	60	25
Barmen	63	25
Heilbronn	60	20

	For light.	For power.
Danzig	60	30
Darmstadt	70	25
Mühlhausen, i. E.	70	29
Brunswick	60	20
Gablonz	48	27
Cassel	70	25
Esslingen	60	20
Neusalza	60	20
Flensburg	60	18
Zwickau	60	20
Ronsdorf	45	20
Homburg	80	20

We see from the above table that the normal unit price for power current is about three times cheaper than that for light. Even here the matter does not rest, for upon these low rates of power current there is still a discount allowed, which makes the normal unit price for light in many cases five times higher than for power.

There is a certain number of central stations which, although having a separate tariff for light and power, allow no discount upon power current, because they are of the opinion that with the low unit rate at which they sell the latter, they have reached the extreme limit. Such central stations have thus carried out, in a certain sense, the idea of a unit rate for energy — when only for power — yet within the limits of this unit rate the consumer is allowed to take whatever he requires and is neither restricted to the amount nor to the time of consumption. That formerly gas companies with their double tariff did not restrict customers to use power gas only in certain hours of the day or night, is easily explained by the fact that gas companies generally have a constant production at all hours of the day, while the delivery of gas is effected through the splendid storage system they possess. This, however, is by no means the case with electric companies, and when they fixed a threefold cheaper rate for power current than for light, while at the same time putting no restrictions or conditions as to the time when such power should be taken, they failed to recognize the logical situation. Central stations have always regarded the sale of current for power purposes

as a welcome opportunity through enabling them to utilize a part of their idle plant during the day; but they soon found out to their dismay that a motor load also exists during the period of greatest consumption, and thus tends to sharpen the peak of the load curve considerably. This nuisance is still more pronounced with stations allowing a liberal discount upon the existing low rate for power current. Taking for example, in the best case, a motor that runs yearly about 3,000 hours, we find that many stations allow in such case a discount ranging from 35 to 40%, which when taken from a unit price of 20 pfennigs per kw-hour, brings the power current price down to 13 or 12 pfennigs. The power consumer thus has with such a low price unrestricted privilege to take as much current as he needs, and at any time he pleases — that is, also during the period of highest consumption — thereby causing heavy installation investments without obtaining the equivalent returns that such investments should bring.

If the demand for power in general were such that each motor would show at least an annual service of 3,000 hours, it might still be desirable to retain the low rate, because a certain part of the plant in central stations could be in service all the year for 10 hours a day, thereby giving a prospect of obtaining a half-way decent return upon such investments. But in the development of power delivery it has been proven that although there is an increase in the number of electric motors connected, there is also a decrease in the average time in which such motors are in service.

The fact that power users have obtained such very low rates, and with no conditions imposed upon them as regards time of service, has encouraged them to go further and to demand the same rates for light as they have for power. The argument that they bring forward is that the light they use and need is likewise necessary in their work, and thus it is also for "industrial" purposes — which statement it must be admitted sounds logical.

If it is possible for central stations to deliver power current at a low rate during all hours of the day without any restriction, why should not this current also be used for lighting purposes? The consumer will and can never understand why he should pay more for the one and same kind of energy when it is used in the form of light and taken at the same time when he takes his power.

A precedent to such demands has already been set by gas companies, who permit customers consuming "industrial" gas, to use a certain limited number of lights taken from the same meter which

supplied the gas for industrial purposes. Such favors were not only given to customers for power gas, but also to those who used gas for heating purposes. For example, customers using gas for cooking, were allowed a burner in the kitchen and one in the hall; and those using gas for heating the bathroom stove were allowed one burner for the room. Gas companies can easily grant such favors, for the price they ask for industrial gas is high, but electrical central stations are thereby forced to accommodate themselves to this custom also, in order to compete with gas effectually, and they too have permitted their power customers to connect a limited number of lamps on their power circuits. Various central stations have tried to induce power consumers using the current for a few hours only in the day, to concentrate their service during the daylight hours, and abstain from using current during the evening period of highest consumption. This plan has in many cases been attended with good results, but the reverse in other cases simply because power consumers flatly declare they cannot accept a proposition in which their time of service is restricted, as the time of their employees is from morning until evening, and that they must pay them for this time, and are thus compelled to operate in the evening. In such cases it was found that many customers whose time of power service was of short duration, generally consumed power only in the evening hours. The preparation of the work for the motor was during the day as long as there was light, and then given over to motors in the evening to finish. It is evident that the more such a class of customers increases, the more burdensome they become to central stations.

Central stations could, however, obviate such unfavorable cases as have just been mentioned, by introducing a "double-tariff meter" whereby the current taken during the period of greatest consumption, say from 4 until 8 in the evening, is charged at a maximum unit rate, while that taken during the other period of the day is charged at a much lower rate. Such a double-tariff system however can only be effectual *when there is a great difference between the maximum and cheaper rate.* If this maximum price for the evening hours is set at a high figure, there is no doubt that power consumers will be alarmed, and perhaps feel inclined to restrict or diminish their power consumption in the evening as much as possible. If, on the other hand, this maximum motor current price is only 20 pfennigs, as up to the present, power consumers see no necessity of putting a special restriction on themselves as to the

time of consumption; and considering the short time they require power, a difference of a few pfennigs per kw-hour is of little account to them. Thus in order to obtain the desired results with a double-tariff system, it is necessary to establish the basic price for power current during the evening hours at as high a figure as possible; in other words, power current must be raised in price. Such an increase in price will thus tend to lead to the ideal of all tariffs — to a unit basic force, abolishing thereby the difference that exists between light and power current.

The advantages to be derived from such a unit price are considerable. It dispenses with the necessity of separate circuits, separate meters and meter rents, different bills for light and power; the investments decrease while the administration becomes simplified. A double-tariff meter is just as expensive, and more complicated than two separate meters, while there remains the double billing and intricate management; the meter rent must accordingly be raised on account of the higher price of double-tariff meters. Should it be desired to introduce a double-tariff simply for power current, in order to ward off short-time consumers from the heavy load period, it will be logical and necessary to establish also a double tariff for light, because the time and duration in which light is employed is also an important factor. This would still involve more complications and instead of two readings of the meter and two bills, there would be required four. Therefore, if it is considered desirable to introduce a double tariff, there remains but one thing to do, and that is, *to establish a unit rate for light and power*, with only this difference, that the unit rate be divided into two classes or steps, according to the time in which the energy is consumed. It is natural that the upper portion of such a double-tariff unit should be pretty high in comparison with the other or lower portion. The consequence of such a tariff system would naturally be to raise the original very low price for power current — at least in the evening hours — and finally also raise the motor price. Such increases in motor current rates have already been introduced in a limited manner in some of the latest current tariffs. For example in Freiburg, Bohemia, current for elevators, lifts, is charged on a double-tariff basis of 60 and 20 pfennigs, while current for light is reckoned according to a unit rate. In Bonn, Germany, a double-tariff system has been introduced for electric motors only, and also on a basis of 60 and 20 pfennigs, while for lighting purposes the double tariff is not used. The Oberlausitz central

station charges for power current at 20 pfennigs; should, however, consumers use less current than an equivalent of 500 hours yearly, the rates go up then to 23, 25, 30 and to 35 pfennigs, according to the number of hours' use in a year. In Elberfeld, a double-tariff system has been introduced both for power and light, and motors pay in the evening hours 55 pfennigs per kw-hour instead of 20, which is the day rate. It may be mentioned that an exception is made in the case of motor customers who guarantee a use of 200 hours in a month; such customers pay the regular rate of 20 pfennigs also for the evening hours. In Düren the double-tariff system is also used for light and power, but is not compulsory; power consumers who can restrict their time of service, so that they require very little or no current at all during the evening hours, have a double-tariff meter and are charged on the 60 and 20 pfennig basis per kw-hour. In Halle a. S. there exists a mixed system of charging, and power consumers who will not restrict their time of service, are charged per year at 60 pfennig per kw-hour for the first 300 kw-hours, and the remainder is charged at a rate of 5 pfennigs per kw-hour. Power consumers, however, who restrict their time of service from 8 o'clock in the morning until 4 in the afternoon are charged only 20 pfennigs for the first 300 kw-hours, and for any excess, 10 pfennigs per kw-hour. In Stuttgart, however, motor current is charged for at 40 pfennigs per kw-hour from 5 to 7 o'clock in the evening, whereas current consumed during the other hours of the day is charged for at 20 pfennigs per kw-hour. In Bremen only such power consumers have a double-tariff meter who use at least 10,000 kw-hours per year. In Wiesbaden, elevators are subjected to a special tax of 2 marks per kw-hour per month. In Cologne, there is a unit tariff for power and light, which in the evening hours is 50 pfennigs and during the rest of the day 20 pfennigs. In Berlin, elevators are subjected to a special tax of 25 marks per kilowatt and year, in addition to the usual current rate.

If, therefore, we wish to encourage a slow and just increase in the price of power current, we must ask ourselves, What effect will such a measure have on the development of motor service? We know from experience that there is nothing to fear from a retrogression in this respect. It is also evident that all intermittent power customers who have a small yearly consumption, will hardly change over to some other form of energy, even when the price for power current is considerably raised or even doubled. Neither will there be a decrease in such a case in the number of new appli-

cations of customers of this kind. The advantages of the electric motor are so well known, and they can scarcely be dispensed with nowadays, even if the cost of service is increased. One of the most formidable competitors, the generator gas motor with its cheap service, has not only made no advance against the electric motor, but has shown that it is not even a competitor of the ordinary gas-motor. We find some very instructive matter in this connection in the 1903 annual report of one of the largest gas companies in Germany, the German Continental Gas Co., where it is stated "that up to the present the generator gas motor with its economy in fuel has effected no decrease in the consumption of coal gas for motors, but just the contrary, as there has been a steady increase in the latter motors, which proves conclusively, that simple economy in fuel-consumption in a motor is not the main factor. Generator gas plants are expensive, they take up more space than a coal gas motor, while their service is more complicated; such facts play in many cases an important part when considering the pros and cons. Then again, in an intermittent service, the coal-gas motor is always ready for action, and there is no fuel consumption when at rest, which is an important advantage. We can thus calmly rest assured, that the generator gas motor will offer no serious competition, even if in the future, especially for motors of large dimensions, it should be improved considerably. The many special advantages that exist in the coal-gas motor service are such, that they will always assert and vindicate themselves." . . . By substituting the words *electric motor* instead of *coal-gas motor* in the above citation, we do not alter the bearing of the facts stated.

The price of power current for intermittent service can thus be safely and considerably raised, while in creating a unit price for light and power there is also room for a discount for continuous motor service. This discount can go so far as to fix the cost of continuous motor service about on a level with that of power current as it is at present. It is known that the yearly average time of service of a connected kilowatt varies between 300 to 400 hours. However, a continuous motor service shows a yearly consumption of about 3000 hours, for which a discount of 35 to 40% is generally allowed. Thus, if the new unit price for electrical energy were fixed at 45 pfennigs instead of the average 60 now usual, and discounts were allowed ranging from 50 to 60% to consumers whose time of service approximate 3,000 hours yearly, we shall find that such discounts will be considered equitable as re-

gards time of service, and the former cheap power rate will then be accorded to those that really deserve it.

It is evident that the introduction of a unit price for electrical energy can only be accomplished by first decreasing the price of current for light. Gradual diminution in the price for light current has already, and repeatedly, been made by central stations, and has always produced good financial results. Where the electric motor need not fear the competition of gas companies in this respect, we are placed in a totally different situation with regard to light. The phenomenal success and introduction of the Auer-Welsbach mantle, together with the decrease in the price of gas, has retarded the advance of the electric light considerably. A standard Auer-Welsbach mantle giving at the beginning 90 to 100 Hefner units, and having an average intensity of about 80 Hefner units, consumes at a gas pressure of 35 mm per Hefner unit, mean horizontal intensity, through an average of 500 hours, 1.5 litres of gas. The price of gas being 12 pfennigs per cubic metre, the cost of a Hefner unit is brought down to 0.018 pfennig. Taking a standard glow lamp having an economy of about 3 watts per Hefner unit, we find it would be necessary to deliver electrical energy at 6 pfennigs per kw-hour if the incandescent lamp were to compete with gas in cheapness. Current for lighting at the present costs about 55 to 60 pfennigs per kw-hour, from which we see that there exists a tenfold difference in price between the two kinds of lighting. Although central stations allow a discount on current for light that varies from 40 to 50% to consumers who have an unusual long-hour service, there is still in such a case a difference of 1:5. On account of the specific advantages that the electric light possess, it has obtained in many fields a hold that cannot be shakened by any cheap kind of competition. But the problem for us to solve is to make the incandescent lamp capable of competition in all fields, *and this can only be effected through a proper decrease in the price of electrical energy.*

DISCUSSION.

CHAIRMAN LIEB: We have before us for discussion a subject which is of interest to all station managers, of whom we have so many here this morning. It is difficult enough to discuss this subject in any of the meetings of our merely national or local bodies; and when, as is the case here this morning, we have representatives from abroad, where all conditions of service, of competition and of local distribution are repre-

sented, that matter becomes doubly difficult. In order properly to discuss this subject, therefore, we should have ten times as much time as is available this morning. We wish to give every one an opportunity to be heard, and, therefore, I will ask that the gentlemen who wish to be heard be as brief as possible.

Mr. L. A. FERGUSON: I would like to ask one question. On the eleventh page of Mr. De Fodor's paper there must be a mistake; in the last line of the first paragraph on that page it says "In Berlin elevators are subjected to a special tax of 25 marks per kw-hour a year, in addition to the usual current rate." That must be kw rather than kw-hours.

Mr. ROBERT HAMMOND: I should think it is kw; it is undoubtedly that.

CHAIRMAN LIEB: This raises a question which we will try as far as practicable to cover in our future meetings by having on the table the original manuscript of each paper. It must be kw.

Are there any other remarks either on Mr. Wright's paper, or Mr. De Fodor's paper. We have some representatives from gas corporations with us, who are operating jointly gas and electricity supply companies, and perhaps they will be kind enough to contribute something toward the discussion.

Mr. PAUL DOTY: I did not intend to take part in this discussion, but I am appreciative of the invitation of the Chairman, and being at the present time a manager of a combined gas and electric light and power property, I am naturally much interested in the papers presented.

The subject of rates is one which has come prominently before the various gas and electric light associations of this country in late years, and the American practice is generally a matter of record. It is of interest to note that the rate problem is in the minds of the foreign managers, and evidently is of as much importance to them as it is to us. It is a pleasure, therefore, to listen to the paper written by Mr. Wright, whose name is so familiar to American engineers and managers, and also to the paper by Mr. De Fodor, on rates for electric supply. I will not attempt a discussion in detail of the subject, but I am impressed that a study of Mr. De Fodor's paper will reveal much that is of interest and value to a gas manager. Gas managers generally have advocated and practiced for years the system of charging a uniform price for uniform quantities of gas, and there is much information in Mr. De Fodor's paper that bears on the practice applied to electric rates.

There are a number of systems of charging for electric current in vogue in America, and one which is quite prominent is based on the idea that the electric business should be considered in part as an investment business; further that there are certain expenses incident to the consumer which should be covered by a direct charge to the consumer; and further a charge for the current based directly on the quantity supplied. It is realized that the manufacturing cost of the current supplied is relatively small, and I believe it to be desirable to make our rates so that the charge to our consumers for current supplied will more nearly approach manufacturing costs, and thus remove much of the suspicion of large

profits in the electrical business, which suspicion may come if a price is made per kw-hr, which includes interest, profit and a consumer's charge. It is our business as managers to encourage the largest possible use of current to bring about maximum net earnings, and it is believed the profitable long-hour consumer can be best obtained and retained by a low rate for current.

As a matter of information and comparison, I desire to add to the statement at the bottom of page 501 in Mr. De Fodor's paper. Mr. De Fodor writes "the gas companies have understood and succeeded in finding new and profitable markets for their products is proven by the fact that the quantity of gas consumed for so-called 'industrial' purposes,—that is, for power and heating—is a relatively large percentage of the total amount generated," and reference is made to the percentages shown in the foreign countries, varying from 34 to 46 per cent. In American practice it is no uncommon result to sell 50 per cent of the total output of gas for industrial purposes, and it was my good fortune while manager of the Detroit City Gas Company to reach results where 70 per cent of the total output of gas was sold for industrial purposes, that is including gas used for cooking and heating with the gas used for power. Apparently American gas managers are making greater use of their opportunities for increasing the output of industrial gas than are their foreign brother managers.

Mr. F. E. GRIPPER: This is a large question, and I should like to throw out the suggestion as to whether the writer of the paper has not reversed the subject. My idea is that it is possible to get down to the single unit, but I throw out the suggestion that the right of way to do it is to decrease the price that you charge for the power supply so that the amount of energy supplied for power would increase to such an extent that you can ignore the amount used for lighting. The amount used for lighting will be so small compared with the total output that you can adopt a unit and throw the lighting in at the same price as the current for power.

Mr. ARTHUR WILLIAMS: It occurs to me to suggest that there is a question as to the accuracy of the statement that as the power business increases the average use of lighting decreases. I do not know where that has been shown in practice, but theoretically it would seem to me to be that almost the contrary would be true: I personally look upon any high unit rate for electricity as meaning a high peak, and any low rate as meaning a broad peak or the absence of a peak. I think the experience of electric light as well as gas companies has been in keeping with the suggestion of the author of the paper, that as the rate is lowered, the financial conditions of the supplying company are improved. I think anything which tends to restrict the use of power is unfortunate. The largest cost in the manufacture of electricity is labor. It is true that in some communities the use of power has been confined to the daylight hours, but that has made it necessary to upset the conditions of labor. I think it much better to advocate the advantages of electric power than to establish artificial barriers to its use. Where we eliminate the use

of power from the darker hours of the day we eliminate also the use of light. I think that we all recognize that the difference between the power rates and the lighting rates is not largely due to the difference in the load factor. The motive behind the user of power is to use the power just as long as he can get work out of his plant; whereas, on the other hand, the use of light is only occasioned by the conditions of the weather, the season of the year, or local conditions prevailing in the premises of the user, which controls the use of light. There is also an amount of competition in the power service which we have always had to a very much larger extent than in the illuminating service of the supplying companies. I think the average use of power in this country, knowing little of what the conditions are abroad, are three hours per day, per unit of use. On page 510 Mr. De Fodor gives two rates—60 pfennigs for the first hour, 300 hours a year, which I take to mean one hour a day, and five pfennigs for any increase over 300 hours per year, or one hour a day. If you take three hours, if that be the average in Germany, you have an average cost in our money of five to eight cents per kw-hour, which is not far from the average price received by the companies here under the same conditions of use.

Col. R. E. B. CROMPTON: In support of what Mr. Gripper has said, in England we have had to compete with gas at a very low price so that in order to tempt custom we have been compelled to fix a low rate and give back large discounts to customers who use electrical energy for long hours. In England we find that the companies which supply current at the lowest prices are those which pay the best dividends.

CHAIRMAN LIEB: It may be of interest to the representatives from abroad to state that the American electricity supply companies are not confronted by the sharp competition of the gas engine with the electric motor, that is found to be the case abroad. In many of our large cities the number of gas engines is on the decrease rather than increase, a situation quite different from that abroad.

Mr. ARTHUR WILLIAMS: May I ask Mr. Crompton what the rates are for light and power in England?

Col. CROMPTON: It differs in different parts of the country. In London, about ten cents per kw-hour is the average rate, with a discount for long hours, and about four cents per kw-hour for power.

Mr. ROBERT HAMMOND: In answering the question of Mr. Williams I may say that one district in London we charge for lighting fourteen cents for the equivalent of the first hour's use and all beyond that at two cents. We thereby get the principle laid down in this paper, of having a time rate, a base rate or time rate, in which every one can participate according to their hours of use. It is fourteen cents for the first hour and two cents per kw-hour for all beyond.

With regard to power, it is stated by Mr. De Fodor that the power peak coincides with the lighting peak. We find that is not so in actual use. We know that the sun goes down at a certain hour and the people turn on their lights, but we find in the use of motors that the peak is not so decided. We recognize that in the district of London, and instead of charg-

ing for power fourteen cents, as for the first hour of lighting, we charge eight cents for the first hour and two cents for all beyond Mr. Williams says that the average use for power here in this country is three hours. We find that the average for power use in London is much more than three hours. Our load factor is 10 to 12 per cent load factor on lighting, which is equivalent to two and one-half to two and three-quarter hours per night, and we find the average of power is much higher. On the fourteen-cent basis the average price for two hours of use comes down to eight cents for lighting; three hours, six cents; four hours, five cents; and for power, with eight cents for the first hour and two cents beyond the first hour, the average for six hours is three cents.

There is one more remark I will make on this paper. I find the author advances the idea that the power should be charged at the lower rate and the lighting should be so much more. I think he overlooks the fact that the cost of production of electrical energy does not consist in coal alone. There is no gentleman who can speak more strongly on this point than the gentleman in the chair (Mr. Lieb), and I believe he will agree with me that the heaviest cost in the production of electrical energy is interest and the wear and tear on the plant, which is very often double the cost of actual daily expenses. Therefore, it seems fitting that the correct charge must be one which loads up on each consumer his share of the capital part of the undertaking, and then the actual running charges will be only light ones.

Mr. L. A. Ferguson: I wish to endorse what Mr. Hammond has to say regarding the justification of the difference in price for power and for lighting customers. Our American practice shows that the peaks of lighting customers are coincident, whereas the peaks of power customers are not coincident. Therefore, the average load-factor of power customers is better than the average load-factor of lighting customers. It will be seen, therefore, that we are perfectly justified in making a lower rate to power customers than to lighting customers, because the cost of supplying energy to customers is dependent upon the load-factor of the system. The better the load-factor of the system the lower will be the cost of production.

Mr. Philip Torchio, New York: In the supply of current for light and power, we have to meet two different conditions; one, that of a load lasting practically uniformly, without peak for, say, ten hours a day, 300 days in the year, for motor service; and the other, a lighting load which has a very pronounced peak of one, two or three hours for the winter months, and varies for different seasons of the year, being largest in the winter months and smallest in the summer months. As long as we have to meet these conditions, it will be necessary to differentiate in the charges for service.

Mr. J. R. Dick: I believe there have been no criticisms, so far, Mr. Chairman, of Mr. Wright's paper; but I will say a few words with reference to the other paper. Mr. De Fodor seems to be under the impression that by obtaining simplicity of tariff, you are thereby securing the best development of the electrical supply business; but I am not of that opinion. For instance, take the case of a man who is manufacturing two or three articles,

if he were content to lump all at an average price, he would be in the dark as to which article he makes a profit on. Commercial analytical methods are for the purpose of determining cost and fixing prices in proportion to cost, and in this way it is possible to render a business more profitable.

With regard to the details of the paper, Mr. De Fodor points out that small electric motors need not fear competition with gas, but I would like to emphasize the way in which this matter had to be tackled in various cities in England. We give a low rate, two cents per kw-hour for power, on the condition that the consumer consents to have his supply cut off during the hours of peak load, in the winter months, the hours naturally varying from month to month. This system is widely used by people who require power and wish to obtain it at low rates. It does not disorganize their factories to utilize power in the winter months up to four o'clock only, as they can arrange their manufacturing processes so that this is scarcely an inconvenience. In connection with the general argument, it seems impracticable to make the same price for light as that for power. For instance, not even Mr. De Fodor would suggest that anybody could supply a tramway undertaking with power for its trolley cars at three cents per kw-hour, and imagine that the rates for private lighting could ever approximate to this figure.

Mr. Arthur Williams: There are so many representatives of foreign companies, including gas companies, present, that I ask the gentlemen if any gas companies in Europe have rates which compare with our electric light rates for light — a high unit price for the first few hours and a low rate for the others?

Mr. Robert Hammond: We deliver it off the machine, but the gas people store their gas; their rate is always a flat rate.

Chairman Lieb: We will now have the paper by Mr. George N. Eastman, of the Chicago Edison Co., the delegate of the National Electric Light Association, on "Protection and Control of Large High Tension Alternating-Current Distribution Systems."

PROTECTION AND CONTROL OF LARGE HIGH TENSION ALTERNATING-CURRENT DISTRIBUTION SYSTEMS.

BY GEORGE N. EASTMAN, *Delegate National Electric Light Association.*

The principal object to be attained in the installation of protective apparatus is continuity of service. While the precautions that are necessary to be taken in the operation of one system may differ materially from that of another, the protective apparatus installed to insure continuity of service would be substantially the same for either system. There is a wide difference of operating conditions in the present large high tension systems, due to the different types of apparatus which are installed. Contingencies which will frequently arise on one system will be infrequent on another. In treating the subject then, it is necessary to outline the general type of the system which is to be considered, principally in regard to the apparatus which it serves.

A system may have overhead and underground lines supplying step-down transformers operating induction motor generators, synchronous motor generators or rotary converters, or it may have induction motor generator sets or synchronous motor generator sets directly connected to the primary distribution system. The combination of nearly all these conditions is obtained in a few large high tension transmission systems now in operation in some of our large cities. It is evident that the contingencies which will arise on such a system will be more varied than the contingencies arising on a system supplying only one class of transmission lines and only one type of translating apparatus. The system of the Chicago Edison Company and the Commonwealth Electric Company is representative of the former class, and as examples and conditions presented throughout this paper will refer particularly to this system, a brief description of the principal features relative to the examples and conditions cited will be given.

The high tension system of the Chicago Edison Company and the Commonwealth Electric Company consists of a 3-wire, 3-phase, 25-cycle, 9000-volt primary distributing system fed with but one ex-

ception by three-phase star-wound generators. The system is operated from two generating plants, the Fisk Street station having at present a normal capacity of 15,000 kilowatts, and the Harrison Street station having a normal capacity of 10,000 kilowatts. The neutral of the 9000-volt generators is brought out and connected to a common ground bus in each station.

The primary distributing lines consist of 43 lines of three-conductor, paper insulated, lead covered cable and one overhead line interconnecting generator stations and sub-stations. With few exceptions, the cables are made up of No. 4-0 conductors with insulation of 6/32-in. paper concentric with the conductor and 4/32-in. paper wrapped over all, jute or hemp filler being used, and the whole treated with a resin oil. The length of underground cables connected to the system is 63 miles. The length of overhead lines, 9.4 miles.

The translating apparatus in the sub-stations consists of 9000-volt, 3-phase synchronous motors direct connected to 60-cycle generators; step-down static transformers operating rotary converters and step-down static transformers driving induction motors for operating exciter generators. A diagram of the high-tension system is shown in Fig. 1.

Grounds on the System.

In the process of installing an underground three-conductor cable, the insulation wrapped over all the conductors is more liable to injury than the insulation concentric with each conductor. Any mechanical injury to the insulation concentric to the conductor is generally confined to the insulation of one conductor and is seldom obtained on all three conductors at one point in the cable. A resultant breakdown in insulation due to mechanical injury is, therefore, more frequent between conductor and ground than between individual conductors. The effect of electrolysis is to produce the same result. As a general rule a small hole is first obtained in the lead which is nearer to one conductor than it is to the other two, and the moisture entering causes a breakdown to ground.

The effects of grounds should be studied, and an effort made to determine the resultant effect which will be produced by grounds in all conceivable cases, in order that proper precautions may be taken to limit the extent of injuries to the system.

On any alternating-current system, the relative potentials which

exist between any part of the system and ground will depend upon the distribution of the electrostatic capacity throughout the system. The insulation resistance is necessarily so high that its effect

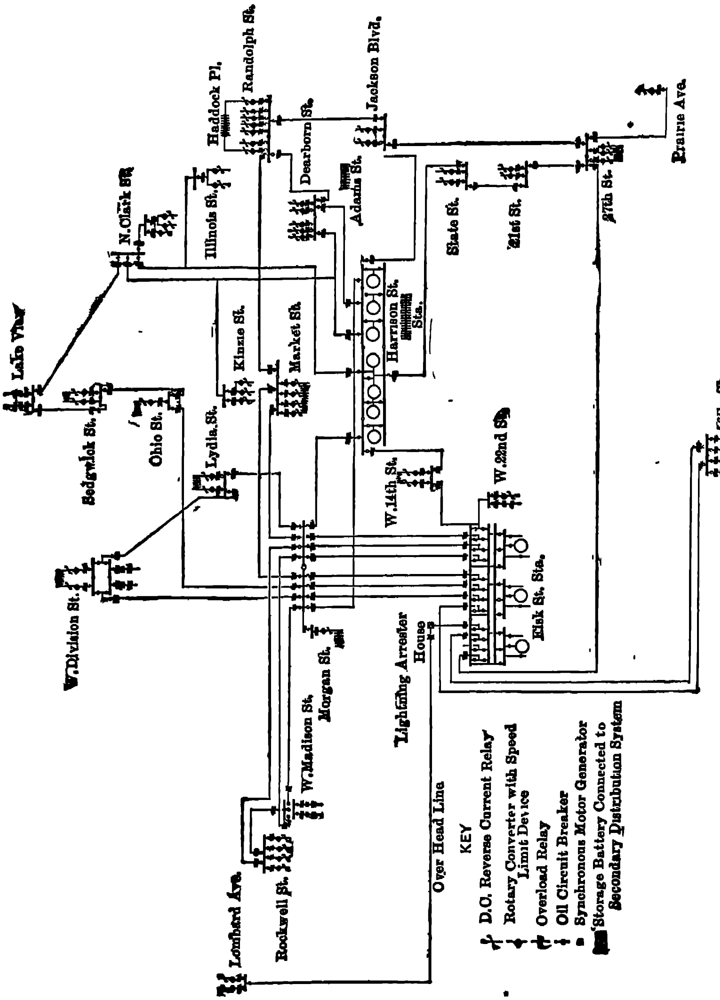


FIG. 1.

in determining the potentials which will exist between the system and ground will not be noticeable.

The condensance of the system performs the function of elastic ligaments, connecting the system to ground. The elastic limit of

the ligaments is the potential at which the dielectric is broken down and a direct short-circuit established. The effect of a ground on the system depends upon the nature of the ground and the value of its reactance in relation to the condenser reactance. An appreciation of the above statement can be best obtained by the presentation of a few examples which might occur in actual practice.

The total capacity of the overhead and underground transmission circuits of the Chicago system is 2.79 microfarads between two conductors, and 10.64 microfarads between each conductor and ground. The capacity reactance (condensance) between two conductors at 25 cycles equals 2285 ohms, and the condensance between each conductor and ground is 598 ohms.

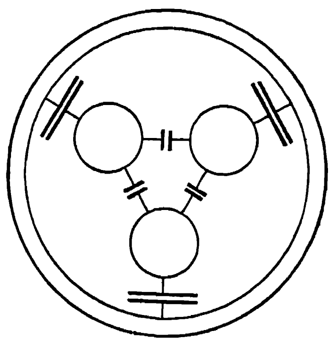


Fig. 2.

Fig. 2 represents the distribution of capacity in a three-conductor underground cable. The lines representing the condenser plates are drawn to scale so that a relative comparison between two conductors and between each conductor and ground is graphically represented. It will be noted that the capacity between conductor and ground which is the factor determining the relative potentials which will exist between ground and system is several times greater than the capacity between conductors.

The distribution of condensance in overhead lines is shown in Fig. 3. In this diagram it is assumed that the line conductors are properly transposed so that the capacity between conductors, considering the entire system, is balanced. It will again be noted that in the overhead system, the capacity between each conductor and ground is greater than the capacity between conductors.

It is interesting to make a comparison between the capacity of

a system with underground cables and the equivalence with overhead lines. If all the lines of the Chicago system were overhead, assuming a distance between conductors of 16 and 25 ins. respectively and a height of 35 ft. above ground, the total capacity of the system between two conductors would be .57 microfarads and between each conductor and ground .65 microfarads. The condensance at 25 cycles between two conductors would be 11,300 ohms and the condensance between conductors and ground 9620 ohms. The ratio of capacity in the overhead system to that in the underground system would be 1 to 16.4 between conductors and ground, and 1 to 4.9 between two conductors.

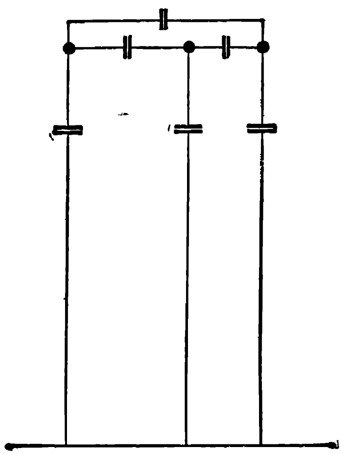


FIG. 3.

Diagram Figs. 4 and 5 represent the arrangement of capacity in relation to the three-phase pressure diagram. As in Fig. 2 and Fig. 3 the condenser plates are drawn to scale, so that a comparison can be made between underground system and an equivalent overhead system.

The effect of a ground on any conductor is to shunt the condensance of the system between that phase and ground, and it is evident that the relative potential which will exist between the system and ground will depend upon the nature and value of the grounding impedance and the relation it bears to the shunted condenser reactance.

An idea of the effect which will be produced by an inductive ground can best be obtained by an inspection of Fig. 6. In diagram

Fig. 6 it is assumed that the condensance of C phase is shunted by inductive reactance having no resistance component. It will be readily conceived that if the inductance is equal to the condensance, that the impedance of the circuit between C and G will be infinite, and the relative potential to ground will be determined by the capacity between the phases A and B. If these two condensers are of equivalent value, the ground will be located at the point G_1 midway between A and B, and the potential from A and B to ground will be one-half the delta potential of the system; the

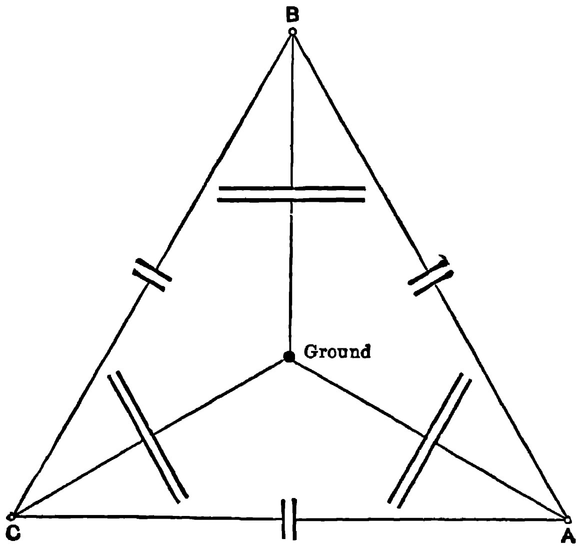


FIG. 4.

potential from C to ground will be 86.6 per cent of the delta potential of the system. As the inductance is decreased it will be evident that the potential between the system and ground will be increased; since the condensers between A and B are in series with an inductive reactance. The potential will increase as the inductance is decreased, until the latter is one-third of the reactance of each condenser. For this value of grounding reactance, the potential between system and ground will be infinite. With a further decrease in the inductive reactance, line G G_2 will swing through infinity and the potential will decrease along the line G G_3 until, when the grounding reactance is zero, C will be at ground potential.

If an inductive ground could be obtained having no ohmic com-

ponent, a ground of 199 ohms on the underground system of Chicago would produce an infinite voltage, and if the system were overhead, a ground of 3206 ohms would produce the same effect. Thus, it will be seen that the factor which determined the relative potential to ground depends both on the grounding impedance and the condensance of the system.

Fig. 7 is a diagram showing conditions which would be obtained when the ground is on the primary of one transformer of a star connected set of transformers. The transformer on which the

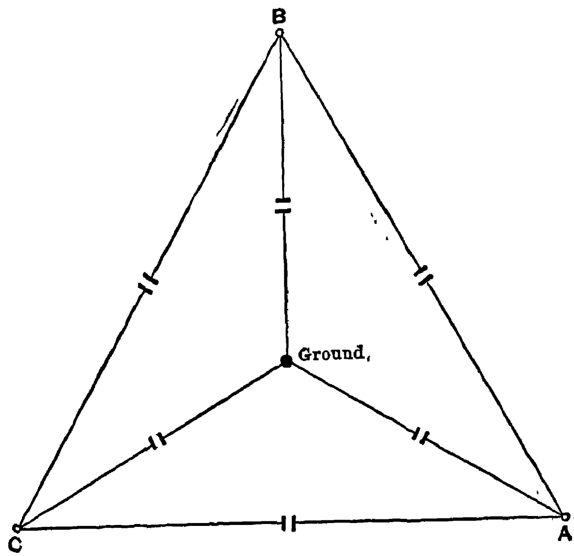


FIG. 5.

ground is obtained is connected between A and the neutral. The curve shown is plotted for a solid ground on the primary for different points along the winding. Condition m_2 would be obtained when the ground occurred in the center of the transformer. Condition m_4 would be obtained when the ground is on the primary, one-quarter the distance between A and the neutral. AL represents the pressure which would be impressed upon the transformer when the ground occurred at the center of the primary winding and CL and BL represent the potentials which would be impressed on the other two transformers.

Fig. 8 is a diagram of the same conditions, considering the system is overhead instead of underground. The results shown in

Fig. 7 and Fig. 8 are for transformers of 200-K.W. capacity each under full load conditions. It will be noted that a ground under the conditions given which would cause considerable trouble on an underground system would cause very little trouble on an equivalent overhead system. The same potentials would probably be obtained on an overhead system with transformers of about 20-K.W. capacity. Much higher potentials may be obtained if at the point where ground occurs an arc is produced.

Grounding the Neutral of Generators.

The remedy adopted for the Chicago system for eliminating the possibility of obtaining high potentials between the system and

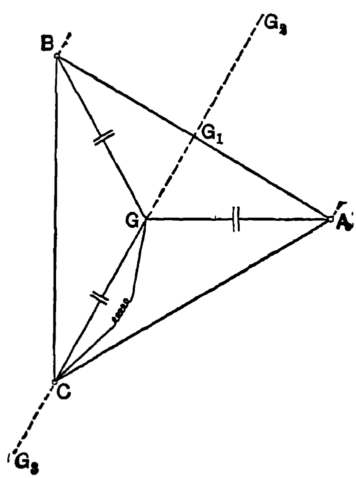


Fig. 6.

ground was the solid grounding of the neutral of all the star-wound generators in the generating stations. It is universally admitted that grounding the neutral will eliminate the chances of obtaining excessive electrostatic disturbances on the system. Fear is expressed by some engineers that with a grounded system, a ground on the system which directly becomes a short-circuit between neutral and one conductor of the generators will result in surging throughout the system, thereby producing results which would be as disastrous as the trouble which it was aimed to eliminate. In some instances a resistance has been installed between the neutral and ground to limit the flow of current to ground. It

is hoped that in this manner the short circuit could so be dampened, that surging would not result. In a large high-tension system it would be impracticable to install a resistance for the purpose of dampening short-circuit oscillations, on account of the enormous current which the resistance would have to take care of.

It would seem that a better system would be the operation of only one generator at a time with the neutral grounded, thus limiting the current which would flow on the occurrence of a ground to the short-circuiting current capacity of that machine.

It should be borne in mind that with the occurrence of a short-circuit which is limited to one conductor and ground, that the

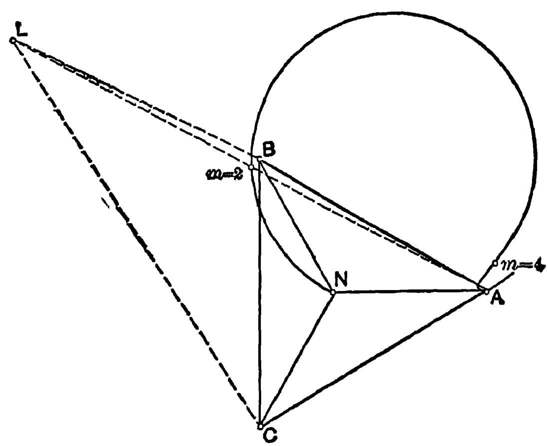


FIG. 7.

energy which is furnished the short-circuit will be supplied by the generators in the generating station and that the synchronous apparatus in the sub-stations, unless their neutrals be grounded also, will furnish no energy until the short-circuit has been translated to between conductors. Thus, if a ground can be detected and removed from the system before it has had time to develop into a short-circuit between conductors, the effect on the system will be greatly decreased. In the operation of the Chicago system, in nearly all cases the short circuits in the underground cable have occurred between conductor and ground, and when the overload relays were not retarded in their action by time limit devices, the circuits on which the trouble has occurred have been opened before the short-circuit was transmitted to other conductors.

Ground Detectors.

The above fact has led to the investigation of a means for obtaining a ground detector which could be used for the purpose of indicating a ground or operating a relay controlling the circuit breaker of the circuit on which the ground occurs. For this purpose the Chicago Edison Company is experimenting with a device, a diagram of which is shown in Fig. 9. This device consists of a laminated iron ring having three independent windings of an equal number of turns, uniformly distributed over the core, and a fourth winding of any desired number of turns which is connected to a meter or relay for providing the desired indications. Each of the three similar windings is connected to the secondary of a line cur-

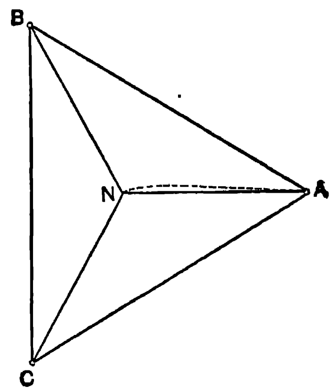


Fig. 8.

rent transformer. So long as there is no escape of line current from the line to ground the currents through the three windings will neutralize each other and no flux will result in the iron core. As soon as the ground is obtained part of the current fed through the transformer will return to the generator through the ground and an indication will be obtained by means of the fourth winding. It is hoped that by means of this with the combination of instantaneous and time limit relays, the line on which the ground occurs will be automatically located and its circuit breaker opened instantly. In this manner the ground may be cut off before the trouble has been transmitted to other conductors and the trouble limited to one line and only that part of the system which is affected by its operation.

Overhead Lines on Connection with Underground System.

The introduction of an overhead line operating in multiple with a large system of cable introduces a very hazardous element and makes it necessary to safeguard the system against atmospheric charges. Every possible precaution should be taken with a view of preventing the transmission of a high potential on the overhead line to the underground system. There is but one overhead line connected to the Chicago system and although it has been in service only a few months several cases of trouble have occurred on it and

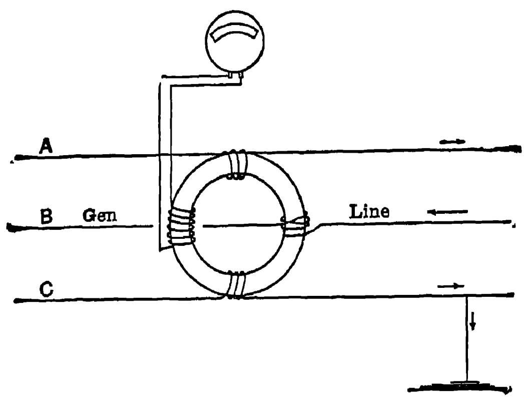


Fig. 9.

the protective apparatus installed has successfully prevented the transmission of trouble to the underground system. This overhead line is connected to the bus-bars at the Fisk Street station through a 900-ft. length of underground cable. At the junction of the underground cable and the overhead line, a lightning-arrester house was built in which were installed choke coils, lightning arresters and a circuit breaker on the line. The choke coils installed had an inductive equivalent of 200 ft. of overhead line. Two banks of lightning arrester were installed, one being connected to the center of the choke coils and the other on the overhead side of the coils. Besides the line circuit breaker in the lightning-arrester house, a circuit breaker was installed in the switchhouse. Care was taken to adjust the overhead relays so that in case of trouble on the line the switch in the lightning-arrester house would be the first to open.

Overload Relays.

One of the most important parts affecting the control of a high tension system is the overload relay which controls the automatic opening of the line circuit breakers. These relays should be capable of selecting the line on which trouble occurs and opening the line instantly. For this purpose a combination of a time limit and instantaneous element is necessary, the time limit feature being set to protect the cable or apparatus against dangerous overloads and the instantaneous device being adjusted to operate only in case of short-circuits or grounds. The time limit devices which have been used without the combination of these two elements have resulted in the operation of circuit breakers of lines on which no trouble has occurred, in some cases shutting down the entire system. In laying out the system, the application of the overload relay should be borne in mind and wherever possible the lay-out should be so arranged that each line receives its energy either over a number of lines, or else directly from the bus-bars of the generating station, in this manner causing the short-circuiting or grounding current in the line on which trouble occurs to exceed in amount the current of any other line on the system. To illustrate this point, referring to diagram Fig. 1 of the Chicago system, it will be observed that there are six lines connecting the Morgan Street sub-station to the Fisk Street generating station. In order to insure these lines remaining in service when a short-circuit occurs on lines connected beyond the Morgan Street sub-station, it will be necessary to set the instantaneous device on the overload relays for current values so high that the sum of the currents in all the lines is in excess of the short-circuiting current which the Fisk Street station is capable of delivering. The time limit element may be set low enough to protect the cable against the continuous overloads which would endanger apparatus and affect the normal operation of the system.

Oil Circuit Breakers.

The application of no other device has played such an important part in making the operation of a large high-tension system possible, as has that of the oil switch. Experiments have shown that with the presence of electrostatic capacity the open arc in air has very destructive effects. Instances have been obtained where, upon opening the circuit in air, arc lengths of from 20 ft. to 30 ft.

have been obtained. Confining the arc in oil, the phenomenon which is obtained with the open arc apparently ceases to exist. This fact should be borne in mind and precaution taken throughout the system as far as possible to limit to a confined space the short-circuiting arcs which are apt to occur. Every precaution should be taken with auxiliary circuits and devices upon which the operation of the circuit breaker depends. The opening of a switch or the falling back of a switch into a closed position may result in as much damage to the system as the most severe short-circuit. The switch should be capable of successful operation through a very wide range in voltage, in order that the control will not become inoperative when trouble on the circuits causes a drop in pressure of the secondary system.

Protection of Translating Apparatus.

The apparatus in the sub-station feeding from the primary distribution system should be protected with overload relays operating circuit breakers, both on the primary and secondary system. With a sudden reversal of current in either a series or a shunt-wound rotary converter the field is apt to be weakened to an extent such that a dangerous speed would be obtained. To prevent this, a speed limit device controlling the direct-current circuit breaker should be installed. To guard against the speeding up of a rotary converter on which the speed limit device has failed to operate and translating its excessive speed to other synchronous machines in multiple with it, the speed limit device should also control the operation of the alternating-current circuit breakers.

To reduce the liability of obtaining excessive speeds on converters, the sub-station translating apparatus should be arranged, wherever possible, so that rotary converters do not operate in multiple with synchronous motor-generator sets connected to the same line. The opening of the line switch in such a case would result in the dropping out of step of the motor, thereby causing the speeding up of the rotary converter due to the demagnetizing action of the heavy lagging current set up in the rotary armature.

In any system care should be taken to prevent the manual operation from interfering with the automatic. The combination of hand and automatic operated devices should be avoided as far as possible, thus minimizing the tendency of the operators to rely upon automatic devices. For example, when

certain cases of trouble arise the automatic devices may be deprived of their means of automatic control and hence fail to perform their functions of protection. In such a case an attempt to operate these devices manually would also result in failure and a loss in time which may cause the wrecking of the apparatus involved, whereas, if the operator had performed the regular routine of manual operation independent of all automatic devices the damage would probably have been prevented.

Every precaution should be taken in the installation of automatic-controlling devices to make their operation independent of the normal service conditions of the system, thus insuring their successful operation under any conditions which may arise.

In conclusion, too much stress cannot be laid on the careful testing of all pieces of apparatus to be installed on the system. All lines and apparatus should be periodically inspected and tested, and no expense should be spared in obtaining correct explanations of the causes of all trouble which arises on the system.

Discussion.

(Mr. Arthur Williams in the Chair.)

Chairman Williams: We are now ready to discuss Mr. Eastman's paper. I think we will follow the excellent example set by the President of this section, and ask you to make the discussion as brief as possible. I do not think it would be wise to cut off discussion to an unseemly extent; but about three or four minutes should be considered a maximum.

Mr. W. C. L. Eglin: I was much interested in Mr. Eastman's paper, as it covered very fully the ground of American practice in protecting devices in the station and translating devices. I was particularly interested, however, in the character of work he has done in locating faults on cables. Perhaps the worse trouble that all of us fear is interference with our underground feeders connecting stations and sub-stations. It is, of course, very important that these troubles should be located just as soon as they develop, or even before they develop, when the cable is about to break down. It would appear from Mr. Eastman's paper as if this was the point they are devoting most of their attention to. The general description, of course, is such as can be applied to most of the central stations of this country; and I shall be very glad to hear how this compares with similar work in the foreign countries.

Chairman Williams: If there is no further discussion on the paper, we will consider the subject closed and proceed to Mr. Eglin's paper.

(Mr. L. A. Ferguson in the Chair.)

Chairman Ferguson: We will now proceed to the consideration of the paper on "Rotary Converters and Motor Generator Sets," by Mr. Wm. C. L. Eglin, of Philadelphia.

ROTARY CONVERTERS AND MOTOR-GENERATOR SETS.

BY WM. C. L. EGLIN, *Delegate Association of Edison Illuminating Companies.*

In the distributing systems of the electric-supply companies in the United States, the demand for low-tension direct-current service is usually of the first importance. The distribution is underground by means of three-wire network, fed from sub-stations located near the load centers; the sub-stations being connected by means of high-tension alternating-current feeders to the main generating station, which is located where the best facilities are available for economical operation. The sub-stations are usually provided with a storage battery, and in some cases with an auxiliary steam equipment, which is used in the event of emergency or for extraordinary loads during the winter months. In most cases, however, where auxiliary steam apparatus is used, it forms part of an old generating station which has been changed to a sub-station.

The percentage of the total load converted for direct current varies widely in different localities, and in the larger supply companies it varies from 30 per cent to 100 per cent. Some of the leading companies also supply power to the sub-stations of street railway companies, and others have a 500-volt power circuit, although most of the direct current is supplied on three-wire 230-volt systems.

In all cases the percentage of the total load converted from alternating current to direct current is large, so that an effective, reliable, and efficient means of transforming alternating current to direct current is essential. The three methods available for this purpose are rotary converters, motor-generator sets, and rectifiers, the first two only of which are available at present for transforming large currents.

ROTARY CONVERTERS.

A rotary converter is similar to a direct-current generator, with taps made on the armature winding and the addition of

collector rings to introduce alternating current. In a single phase rotary converter these taps would be made 180 deg. apart; for two-phase, 90 deg., and similar arrangements for polyphase systems. In most of the larger rotary converters using three-phase systems, the phases are split so as to use six phases on the rotary converter, and in that way increase the capacity of the machine. The efficiency of the rotary converter is higher than of the direct-current generator, for the reason that part of the current passes directly through the windings. The rotary converter must be operated in synchronism with the generator, and when started from the alternating-current side has all the characteristics of a synchronous motor. The rotary converter may be either shunt-wound or compound-wound. The voltage at the direct-current end of the shunt-wound type depends upon the voltage of the alternating current delivered to the collector rings, and practically cannot be varied without varying the alternating current impressed on it. Varying the field strength has the effect of changing the power factor, making the current either leading or lagging without materially changing the voltage delivered on the direct-current end. This necessitates some form of regulator on the alternating-current side so as to control the voltage on the direct-current end of the rotary. There are two methods, either the introduction of induction regulators in the alternating-current leads on each phase of the rotary, or dial switches on the step-down transformers, which vary the ratio between the primary and secondary winding. The step-down transformers are arranged so as to deliver the proper voltage for the e.m.f. desired on the direct-current side of the rotary; and, therefore, a rotary converter equipment consists of step-down transformers, regulators, and the rotary converter, with the necessary switches and safety devices.

Means must be provided for starting the rotary converter and bringing it to synchronous speed. The rotary may be started from either end, preferably from the direct-current side. When starting from the alternating-current side, the current required exceeds the full-load current usually from 50 to 100 per cent; and some means must be provided for controlling this large current; also the field must be cut out until synchronous speed is obtained.

When started from the direct-current side, the machine is started similar to the direct-current motor with variable resistances in the armature circuit, which is gradually cut out as the machine accelerates in speed. The rotary is then synchronized with the alternat-

ing-current generator similar to the operation of paralleling two alternators. Starting arrangements may be common for a number of rotaries, and this is arranged for by switches on the switchboard.

A third method which has been used on large rotary converters is the starting motor, using an alternating-current motor of the induction type to bring the machine up to synchronous speed. When only one rotary converter is in use, and direct current is not available for starting, and the rotary is, therefore, started from the alternating-current side, care must be exercised to test the polarity, as it is very probable it may be reversed. This can usually be rectified by opening the switch on the alternating-current side, allowing the machine to slip a pole.

The rotary converter meets all of the commercial conditions demanded of it, and is capable of delivering current on the direct-current side at from 110 to 600 volts. It can be operated on varying frequencies from 25 to 60 cycles successfully. Rotary converters operate better at the low frequencies for reasons which will be discussed later.

In the early introduction of rotary converters, difficulties were met which were principally due to hunting, usually caused by variations in the angular velocity of the generator. This caused a swing action of the revolving part of the rotary converter, which generally increased unless some means were provided to dampen this effect. The effect of hunting causes excessive sparking at the brushes, and when hunting becomes excessive the machine will flash over at the commutator and short-circuit the direct-current side of the machine; and unless safety devices are provided the machine is liable to be destroyed. The difficulty of hunting has been overcome by the addition of bridges between the poles of the machine. The design of these bridges was capable of being varied so as to increase the dampening effect required. The first form was a copper bridge placed between the poles, but it was found that additional dampening effect was required. The poles were then undercut and copper bridges were extended under the pole tips. The most powerful form consisted of a copper bridge imbedded in the pole face. The addition of bridges usually reduced the efficiency of the machine; rarely, however, exceeding 1 to 1½ per cent. The proper remedy for hunting is naturally the removing of the cause by obtaining a uniform rotation of the generator, which can be accomplished by the combination of an effective governor and the necessary fly-wheel effect on

the engine. Hunting does not seem to take place when the generators are driven by either steam or water turbines. A number of rotary converters have failed owing to the killing of the field, due either to the circuit being open or to the effect upon the field caused by disturbances on the alternating-current side, thus allowing the machine to exceed its normal speed, or. in other words, run away. These failures have required the installation of auxiliary apparatus and of safety devices, which are usually installed as follows:

A circuit-breaker on the direct-current side arranged to trip with excessive overload, which cuts out the rotary in the event of its flashing over at the commutator; and speed-limiting devices to trip the circuit-breakers on the alternating-current and direct-current sides. In some cases the alternating-current side of the rotary is provided with an overload and reverse-current circuit-breaker which trips when the current is reversed; or, in other words, when the rotary is running inverted, supplying alternating current to the line and taking direct current from the substation.

There are a number of different forms of speed-limiting devices, both electrical and mechanical. One form of electrical device consists of a differential relay, one set of coils being connected to the alternating-current bus and the other set to the collector rings. In the event of the rotary exceeding its speed, the frequency at the collector rings will increase, causing an unbalance at the relay and tripping the circuit-breakers. The mechanical devices usually consist of some governor attachments which make contact in the event of the shaft running above its normal speed and tripping the circuit-breakers. Various arrangements of the field wiring so as to allow combination separate and self-exciting connections have been tried so as to prevent errors on the part of the operators.

The study of the rotary converter from an operating standpoint early indicated that the machine had a high inherent efficiency; that the voltage and load could be easily regulated and the power factor adjusted to suit the best operative conditions of the system, and that the first cost of the outfit was comparatively low. For these reasons it was extensively used, especially for frequencies of 25 cycles.

MOTOR-GENERATOR SETS.

Before the rotary converter had been fully developed, a number of these machines were installed on systems with frequencies of 60 cycles; and at this frequency the difficulties due to hunting were greatly increased, and in some cases satisfactory operation could not be obtained. This led to the introduction of the motor-generator sets. The first motor-generator sets were installed so as to obtain the most reliable equipment irrespective of the cost or efficiency. These equipments consisted of a low-voltage polyphase induction motor, direct connected to either one or two direct-current generators mounted upon a common base. The motors were arranged with stationary coils and squirrel cage winding on the rotor, and they were similar in most respects to the small motors which have been used successfully for a variety of purposes. The generators were of standard design and the motors were built to suit the speed of the generator; the motor being supplied with low-voltage current from step-down transformers. On account of using induction type motors the difficulties due to hunting were removed, and the operation in the sub-station was further simplified by having no electrical communication between the direct and alternating-current sides, thus removing the dangers of the machine running away.

The motor-generator sets can be started either from the direct or alternating-current side, by using the generator as a motor and placing a variable resistance in the armature circuit similar to the method used in starting the rotary converter. When the set is started from the alternating-current side, some current-limiting device is introduced in the alternating-current circuit leading to the motor. It has been found of advantage in practice to synchronize the larger motor-generator sets so as to prevent any sudden rush of current when throwing the motors on the system. As the usual methods of synchronizing are not suitable for this purpose, a disc with white and black stripes is attached to the shaft and with an arc lamp connected to the alternating-current bus, the set can be readily synchronized and at synchronous speed the black and white stripes are readily visible. By the attachment of mirrors to the pillow blocks of the various motors, each set can readily be synchronized by the switchboard attendant. Bringing the machine to synchronous speeds is not essential, although it is recommended for the larger size units; that is to say, machines of

400 kw or larger. It has been found advantageous to start both generators and rotary converters from the direct-current side with a starting bar operated by hand, thus reducing the amount of current required to overcome the friction of rest about one-half. This is often important when the sub-station is heavily loaded and the current is drawn from it to start additional machines. It also reduces the size of the starting resistance; for example, 400-kw motor-generator sets or rotary converters may require from 400 to 600 amperes to start them from rest, providing the machines have been standing for some time, and thus the oil allowed to squeeze out between the bearing and the shaft. With the assistance of the starting bar this current can be cut down to 200, and not exceeding 250 amperes at 230 volts.

The operation of these motor-generator sets was all that could be expected of them and was satisfactory in all respects; but, on account of their inefficiency and high first cost, improvements were demanded.

A very rational step was the abolishment of step-down transformers and the substitution of a high-tension for the low-tension winding on the motors; the introduction of one 250 to 300-volt generator instead of two 125 to 150-volt generators, and, in some cases, the substitution of a synchronous motor for an induction motor.

The use of the high-tension winding on the motor removed the necessity for and cost of the step-down transformers, and more than compensated for the additional floor space required by the motor-generator set. Regulators on the alternating-current side were unnecessary — the voltage on direct-current generators being readily controlled by a rheostat on the shunt field — and the operation was simplified, allowing the equipment to be handled by the regular class of dynamo operators, this being of great importance in large systems, as it requires less time to train the operators. Disturbances on the alternating-current side of the system have little effect on the motor-generator sets and are of such a character that they are easily provided for by protecting devices.

The objection to motor-generators, especially those of induction type, is the low-power factor, which increases the losses in the feeders. The losses in the feeders are usually a small part of the total loss, so that this in many cases is not important.

The first cost of motor-generator sets is usually somewhat higher than of rotary converters, particularly in the large sizes. The

actual difference, however, is not so great as is generally supposed. The relative costs of the various sizes are shown in the following table:

COMPARATIVE TABLE OF COSTS.

Rotaries with transformers and regs.		Synch Mt. Gen.	Ind Mt Gen.	Synch Mt Gen	Ind Mt. Gen	
25 Cyc.	60 Cyc.	25 Cyc.	25 Cyc.	60 Cyc.	60 Cyc.	Capacity.
1.00	1.05	1.05	1.10	1.03	1.08	1,000 kw
1.00	1.00	1.05	1.05	1.00	1.00	500 kw.
1.00	.95	1.00	.95	.95	.95	250 to 300 kw.

This is based on quotations by the same manufacturer of rotary converters and motor-generator sets of 25 and 60 cycles, with a 25-cycle rotary converter with transformers and regulators as a unit.

The following table shows the efficiency of a 400-kw, 60-cycle rotary converter and a 400-kw 60-cycle motor-generator set with both high and low-voltage motors. These tests were made at the works of the manufacturers, and show that even at high frequencies the rotary converter is more efficient than the motor-generator set:

Rotary Converter.

Two-phase, 16 poles, 400 kw, 450 r.p.m., 230 to 300 volts rotary.

Two-phase, 60 cycles, 5000 volts primary, 210 to 160 volts secondary transformer.

Per Cent.	Combined Efficiency.	
Load.	at 210 Volts.	at 160 Volts.
100	89.6	90.5
75	88.0	88.9
50	84.3	85.5
25	73.0	75.3

Motor-Generator Sets.

Direct current, 10 poles, 400 kw, 450 r.p.m., 125 to 150 volts.

Alternating current, 16 poles, 560 kw, 450 r.p.m., 380 volts.

Per Cent.	Combined Efficiency
Load.	at 150 Volts.
100	82.0

Direct current, 10 poles, 400 kw, 450 r.p.m., 230 to 300 volts.

Alternating current, 16 poles, 560 kw, 450 r.p.m., 220 volts.

Per Cent.	Combined Efficiency
Load.	at 300 Volts.
100	84.9

Direct current, 10 poles, 400 kw, 450 r.p.m., 230 to 300 volts.
Alternating current, 16 poles, 560 kw, 450 r.p.m., 5500 volts.

Per Cent. Load.	Combined Efficiency at 300 Volts.
100	86.9

After these machines were installed in the sub-stations, a series of tests were made, using the same observers and the same instruments (the instruments being checked between tests), so as to obtain the all-day efficiencies when operating under commercial conditions; the rotary converters being placed in one sub-station and the motor generators in another, but both supplied from the same generating station. It would appear from these tests that there is no practical difference in the commercial efficiency between the high-voltage motor- generator set and the rotary converter, and, as was to be expected, the low-voltage motor-generator set was the most inefficient.

ALL-DAY EFFICIENCIES UNDER COMMERCIAL CONDITIONS.

	Type of Mach'ne.	Load.	H. P.	Eff.	— Power Factor.— A Ph.	C Ph	Av.
No. 1	Ind. Motor	Empty	0	0.0	0.0	45.9	23.0
	Two-phase	1/4	140	72.9	67.1	86.4	76.7
	H. P., 560	1/2	280	82.1	83.6	92.8	88.2
	Volts, 220	3/4	420	85.3	86.4	90.4	88.4
	Amp., 1150	Full Ld.	560	85.4	88.7	92.1	90.4
No. 2	Ind. Motor	Empty	0	0.0	3.9	29.1	16.5
	Two-phase	1/4	140	72.7	56.9	69.7	63.3
	H. P., 560	1/2	280	81.2	77.4	82.5	80.0
	Volts, 6000	3/4	420	84.7	82.5	86.2	84.3
	Amp., 47	Full Ld.	560	85.9	85.6	88.9	87.3
No. 3	Rotary	1/4	134	70.9	99.2	106.0	102.6
	Two-phase	1/2	268	77.2	100.5	105.1	102.8
	KW, 400	3/4	402	80.4	97.4	102.4	99.9
	Volts, 250	Full Ld.	536	84.1	97.6	98.0	97.8

CONCLUSIONS.

The type of machine to be installed in sub-stations depends principally upon the frequency of the system and the importance

of reliable and continuous service. The frequency to be used depends upon other conditions which are outside the scope of this paper.

In cases where the largest percentage of the output of the generating station is to be transformed to low-tension direct current, 25-cycle rotary converters should be installed on account of their higher efficiency and lower first cost. The very large number of these machines which are now in successful operation proves conclusively their reliability and effectiveness. In mixed systems, and where the percentage of current transformed for low-tension distribution is small, motor-generators are desirable. With higher frequency, particularly 60 cycles, it has been shown that motor generators compare favorably in efficiency and are much more reliable and simple in their operation.

Discussion.

Chairman Ferguson: Mr. Eglin's paper is now ready for discussion. You know that in Europe motor generator sets are used very much more extensively than in this country, and we shall be glad to hear from any of our European friends as to their experience. Col. Crompton, we will be glad to hear from you.

Col. R. E. B. Crompton: I am unable fully to discuss this important subject as I have not studied the paper sufficiently carefully but I can communicate one figure which appears important — that is, that in the large London system with which I have most experience, where we generate and transmit at 5000 volts transformed by motor generator sets to 400 volts, and charge batteries through these sets; the total losses, including those in the high-pressure mains, motor transformers, accumulators, low pressure mains to consumers, amount to 27 per cent as a maximum, but about 25 per cent on the average. If we used rotary transformers, these losses would be greatly reduced.

Mr. Philip Torchio: In comparison with the efficiency obtained from motor-generator sets, I would say that with 25-cycle rotary converters of 500 to 1000-kw capacity, in American cities the all-day efficiency is above 90 per cent.

Mr. M. J. E. Tilney: The writer mentions that he only starts up from the direct-current side, owing to the heavy starting current. There is a large system in London where they start up from the high-tension side, with resistance in the rotors, and they find the maximum current never exceeds the full-load current of the machine, and in many cases is only 60 per cent. Is there any special advantage in starting from the direct-current side?

Mr. Philip Torchio: I want to add another point, and emphasize a matter that Mr. Eglin touched upon in the paper, but in my opinion, did not dwell upon strongly enough; that is, the advantage of the greater

capacity you get from a rotary converter than from a motor generator set for overload conditions. This is an important factor in laying out the reserve capacity for a sub-station.

Mr. EGLIN: The figure given by Col. Crompton is similar to the figure in this country on motor-generator sets. As to the question of cutting down the starting current, it is not the practice in this country to start from the alternating side. As the motor-generator sets are started from the direct-current side, the starting current would be much smaller than 60 per cent of the full-load current of the motor. It would not exceed 25 per cent. The motor-generator sets are started in the same way as the rotary converters are started, using the generator as a motor.

CHAIRMAN LIEB: Our time this morning has been very limited To-morrow morning we will open the proceedings at 9:30 o'clock. All the papers which are to be discussed to-morrow are in print, and members can have copies of them. We are going to have a very complete discussion on direct and alternating-current distributions; and you know that such a discussion will take much time, so I will ask you all to be prompt in attendance.

TUESDAY MORNING SESSION, SEPTEMBER 13.

Chairman Lieb called the meeting to order at 9:30 a. m., and announced that the session would be opened by a paper on "The Prussian System of Electric Train Lighting" by Herr Carl Roderbourg, to be read by Prof. Sever.

Prof. Šever then read the following paper:

THE PRUSSIAN SYSTEM OF ELECTRIC TRAIN LIGHTING.

BY HERR CARL RODERBOURG.

The Prussian State Railways, including the Hessian Railways, are operated under a common financial administration, have a length of 31,276 kilometers. Their rolling stock comprises 13,196 locomotives, 24,307 passenger cars and 294,636 freight and baggage cars. The lighting of the locomotives and passenger cars has heretofore been exclusively by oil gas (Pintsch system), to which recently $33\frac{1}{3}\%$ of acetylene has been added to increase its illuminating power.

Experiments with the electric lighting of the Prussian Government Railways have been proceeding for some time, but on a very small scale, while various private railroads in Prussia had equipped their trains with electric lighting. The Prussian Ministry of Railways assumed a waiting attitude and limited itself to the study of the experiments made by other railroads and particularly those in America.

On November 8, 1900, there occurred an event which brought forward the question of electric train lighting in its application to the Prussian State Railways. In a train collision at Offenbach, near Frankfort-on-the-Main, a number of cars were set on fire, and the conflagration spread with such rapidity that many lives were lost. The public and the press attributed the main cause of the rapid spread of the fire to the escape of gas from the tanks under the cars, a fact which was, however, contradicted by the railroad administration. The matter was also officially discussed in the Prussian House of Representatives, and while it did not appear that the danger from the gas tanks had been clearly proven, it was decided by the administration of the Prussian State Railways as a result of this accident to proceed energetically with experiments in the introduction of electric train lighting.

Privy Councilor Herr Wittfeld in the Prussian Ministry of Railroads laid down the following fundamental principle to be followed in the experiment: "No automatic switches or regulating apparatus shall be used in electric train lighting." Although the

Prussian State Railway administration made no objection in exceptional cases to the conduct of tests with lighting systems which did not comply with this general principle, it was generally adhered to.

Credit is due Herr Wittfeld and Herr Dr. Büttner of the Accumulatorenfabrik Aktiengesellschaft that it was made possible to light railroad trains and single cars by electricity without the use of automatic regulators and switch apparatus and without handling an excessive weight of storage batteries. With this system electric current for the incandescent lamps is produced by the well-known method of having one or more dynamos on the train itself. Connected in parallel with them are storage batteries hung under the cars, which in case of need supply current for the lamps, and which may be recharged by the dynamos.

Following a suggestion of Herr Wittfeld, Herr Dr. Büttner has succeeded by the use of special apparatus in avoiding variations in illuminations noticeable to travellers, notwithstanding the difference in e.m.f. of the storage batteries during charge and discharge, and securing constancy of pressure at the lamp terminals without special regulation notwithstanding the variable speed of the dynamos.

Although there is a loss of energy inherent in the system, it offers the advantage of complete reliability in operation and simplicity in handling; and the Prussian Railway administration is of the opinion that more importance should be attached to this reliability in operation than to the increased energy consumption which is small relatively to the whole train. The principle of the constant e.m.f. at the lamps with variable e.m.f. of the source of energy is attained by the insertion of very small iron wire in the circuit of each incandescent lamp. The wire is in small glass pear-shaped globes like incandescent lamps, containing hydrogen gas. By varying the pressure of these gases as well as by the adoption of a special spiral form of wire, the temperature of the wire when current is passing is brought to the proper point. If an iron wire is heated by electric current to a point at which it becomes barely visible in the dark, its electrical resistance increases with extraordinary rapidity with further increase of temperature. If the e.m.f. increases, the temperature of the wire increases instantly and consequently its resistance, so that within considerably wide limits of e.m.f. little more current is allowed to pass than in the case of low e.m.f.

If such a wire is connected in series with an incandescent lamp,

the e.m.f. at the terminals can be considerably increased without subjecting the lamps to an excessive current. Such an iron wire resistance had been previously in use by the Allgemeine Elektricitats Gesellschaft to steady the Nernst lamps in the ordinary lighting circuits. Herr Dr. Büttner has first applied the method to incandescent lamps and for much greater variations in pressure.

The variations in current which result from the insertion of iron wire in series with incandescent lamps is shown in the following table for various e.m.fs.:

VARIATION OF CURRENT WITH E.M.F.

Line E.M.F.		Current.	
56	Volts	8.0	Amp.
58	"	8.1	"
60	"	8.2	"
61.6	"	8.3	"
63.6	"	8.4	"
65	"	8.4	"
70	"	8.41	"
72.5	"	8.43	"
76	"	8.46	"
82	"	8.5	"
83.5	"	8.55	"
84.9	"	8.6	"
86	"	8.7	"

Owing to the fact that the variation of pressure due to the use of storage batteries in train lighting is very much less than indicated in the above table, and moreover takes place slowly, the variations in the illumination of the cars are not perceptible to the eye under such conditions.

Two through trains connecting Berlin and Hamburg on the Prussian railway system, and subsequently two additional trains on the same line, and finally two trains between Berlin and Stettin, were similarly equipped. The trains are always operated as a unit, and each train is equipped with only one shunt dynamo which is mounted on the boiler of the locomotive and driven by a 20-hp De Laval steam turbine.

The dynamo is coupled to the reduction shaft of the turbine, the turbine disk making 20,000 revolutions per minute, while the dynamo runs at 2000 revolutions. The dynamo develops 180 amp.

at 68 volts, but can develop continuously a greater output and at a higher e.m.f. in order to charge the storage batteries. The storage batteries of the Accumulatoren Fabrik A. G., Berlin, are connected in parallel with this dynamo; a battery of 32 cells with a capacity of 76 amp.-hours at a 3-hour discharge rate, is hung under each car. The storage batteries act mainly as a reserve; they become operative only when the locomotive becomes separated from the train or the dynamo should fail for any cause.

The maintenance of the whole equipment is very simple. The engine-driver starts his turbine at a certain hour, connects the circuits and gives no further attention except in case he desires to charge the storage battery when he cuts out the resistance in the field circuit of the dynamo. The switching on of the lamps is done generally by the porters, partly also by the passengers. This arrangement has operated satisfactorily from the start. In the meantime the Prussian Railroad administration has gone a step further and for the following reasons:

The system under consideration if adopted on all through trains would necessitate the equipment of all the locomotives of freight trains. The number of these locomotives is much greater than the number of trains owing to the fact that the locomotives are often changed on long hauls. On the contrary the baggage wagon at least accompanies the train on the whole run. It appeared desirable on this account not to install the dynamo on the locomotive but in the baggage car, and in this way the number of dynamos required could be materially reduced. To drive the dynamo by any form of engine power, a benzine engine for instance, appeared too complicated. The most convenient form of drive is no doubt that from the car axle. This requires that the dynamo be operated at not even approximately constant speed.

Furthermore, there are a number of through cars, which in transit are transferred from one express train to another in order to avoid change of cars to the passengers between main points having no direct express connections. These through cars often run beyond the jurisdiction of the Prussia State Railways, into Saxony, Bavaria, Switzerland, Italy, etc., etc. If it is desired to furnish these with electric lighting, it can be done only if they are equipped each with its own dynamo, which must be adapted to the various lighting systems in use on the different express trains to which they may be coupled. In this case the only possible method of driving the dynamos is from the car axle.

All similar systems hitherto used are equipped with a circuit-breaker which interrupts the current if the speed of the dynamo falls below a certain limit, in order that the storage battery, whose e.m.f. is greater than that of the dynamo at low speeds, may not discharge into the dynamo. This circuit-breaker is automatic and is liable to derangement on account of shock, and it does not therefore conform to the Wittfeld principle, above cited. Herr Dr. Buttner, therefore, substituted for it a so-called unipolar or electrolytic rectifying cell. The electrodes of such a cell consist on one side of aluminum, and on the other of any metal not soluble in the electrolyte of the cell. It is well known that aluminum has the remarkable property of cutting off a current even of several hundred volts if sent through the aluminum into the electrolyte in a positive direction, but allows the current to pass almost without diminution if the direction is reversed. The selection of the electrolyte is important, most of them in the course of time attacking the aluminum and destroying the electrode. Others have the peculiarity that the effect of the aluminum plate ceases when the temperature exceeds 40–50° C. Herr Dr. Büttner has succeeded, after experimenting with many different solutions, in finding a mixture which does not attack the aluminum plate nor diminish its efficiency even should the temperature rise above 70–80° C.

As a second electrode he uses iron plates in his cells and these aluminum cells, which act as a check valve in his train lighting system, are inserted in place of the automatic circuit-breakers. While the e.m.f. of the dynamo preponderates, it sends current through the aluminum cell into the line. The drop in the aluminum cell may then reach as high as three volts. If the speed of the dynamo diminishes and its e.m.f. falls below the terminal voltage of the battery, the aluminum cell cuts off the current and the dynamo may come to rest or even have its rotation reversed without permitting current from the battery being sent into the dynamo and wasted.

An arrangement is in addition applied to the dynamo to provide for the case of a car going in the opposite direction, the commutator brushes being carried forward until a point is reached at which the dynamo generates current in the same direction as before. This arrangement can be avoided if, in accordance with the suggestion made to Herr Dr. Büttner by Herr Liebenow, four aluminum cells are used instead of one in the conversion of alternating into direct current. In this case, however, the drop may reach six volts. An-

other arrangement is in preparation by which this also is avoided. The dynamo, which in general is designed as a shunt machine, is supplied with the supplementary main circuit working on the fields which lowers the e.m.f. if the current becomes excessive. In this way the excessive charging of the storage battery at very high speeds is prevented; otherwise the arrangement is as above described. At the present time two trains are being operated between Berlin and Cologne on which the dynamo is installed in the baggage wagon, driven from the car axles by belts. Several through cars are now in construction in which the armature of the dynamo is mounted directly on the car axle.

The following instructions are given for the maintenance of the equipment:

(1.) The ball bearings should be inspected every two weeks at first and then every four weeks to ensure that there is a sufficient supply of vaseline. The ball bearings should be cleaned and supplied with fresh vaseline every six months.

(2.) The polecharger on the armature shaft must allow of easy motion in both directions by turning the armature.

(3.) The commutator should be kept round and smooth.

(4.) The carbon brushes should be held firmly by the brush holders and impinge on the commutator with a gentle pressure.

(5.) The belt should be tested particularly at the joint to confirm its satisfactory operating condition.

(6.) The wood driving pulley should be inspected as regards tightness on the shaft.

(7.) The screw shaft of the belt tightener should be properly oiled and after tightening of the belt should be secured.

(8.) The dynamo bearings must not heat so as to be uncomfortable to the touch. If a bearing heats, the belt should be slackened until the dynamo no longer rotates. The storage batteries should be handled in accordance with the specific instructions. The specific gravity of the solution should be measured every eight days in order to ascertain if the batteries have received sufficient charge while en route. If the specific gravity of the solution is too low, the e.m.f. of the dynamo should be increased. If the car follows a new route, it is recommended that a measurement be made at the end of each trip.

With regard to the proper treatment of the polarising cell, it is of importance to keep the plates always covered with the electrolyte by about half-an-inch. For replenishing the cell, use liquid

ammonia of 0.94 sp. g. This becomes necessary about every 3 — 8 days according to use. When the cell becomes heated in operation, it allows current to go through it, and liquid ammonia must be added more frequently. Should the cell become much heated, the electrolyte must be renewed. The old electrolyte can be used again after it has cleared. When a car equipped with a polarising cell is to be used again, after a period of rest, the electrolyte in the polarising cell must first be mixed with liquid ammonia. After this is done a resistance must be inserted between the storage battery and the polarising cell. For this purpose the switchboard carries a switch which is labeled "polarising cell." This process must always be carried out as stated, because otherwise at the first moment a large current would go through the polariser.

As the illumination of the cars is very abundant, and as special reading lamps, which can be switched on or off by the passenger, are attached to the backs of the division between every two seats, the electric lighting of the trains is very popular with the public, and in a number of instances letters have been sent to the Royal Prussian Ministry of Railways expressing appreciation of the improvement. The administration is much pleased with the experiments and is proceeding steadily with the equipment of additional trains and single cars. It is therefore probable that the Prussian Railways Department will gradually equip all of its trains with the electric light, and that electricity will in the near future achieve in this field also a victory over all other methods of illumination.

Discussion.

Chairman Lieb: The paper before you is an interesting one, giving in outline what has been done in Germany in the matter of electric train lighting. The system described has the features of simplicity and success, and is an example of those cases where merely theoretical efficiency does not necessarily handicap a very valuable application.

Col. R. E. B. Crompton: Twenty-two years ago the question of train lighting by electricity was considered by me among other manufacturers of electrical apparatus to be of great importance to us. Even then the opinion was held in England that the Pintsch system of gas lighting was dangerous, on account of risk of fire to the passengers, but I think this has been since found to be untrue. The gas lighting of railway carriages is so satisfactory in England that it is not easy for electricians to persuade railway companies to change from that system in order to adopt electric lighting, which after all does not present such very great advantages. At the time that my firm discontinued strenuous efforts to push electric train lighting, we had arrived at the conclusion that the complications of pro-

viding generating machinery attached to one portion of the train ought to be avoided. That if we wished to light all railways on a simple and interchangeable system, it would be advisable to set up a single accumulator system throughout, and provide standard boxes of accumulators which could be pushed into position in proper receptacles made in all the cars at a sufficient number of charging depots which would be provided at suitable intervals along all lines of railway.

Prof. G. F. SEVER: I might add a brief outline of the situation in this country. The scheme seems to be, in two systems that we have, to operate a dynamo from the car-axle, and use the system in conjunction with storage batteries carried on each car. We also have another scheme, which is in use on some of the through trains between Chicago and New York, and out of Chicago in the other direction, of a steam engine running a dynamo in the baggage car and lighting the train without the use of storage batteries. When the train pulls into the station, connection is made to the local lighting system, on account of the engine not receiving any steam from the locomotive. But the axle-lighting scheme seems to be the predominating one, and the one which is being introduced most extensively in this country. Both of these systems are exhibited at the Exposition in the Palace of Electricity.

CHAIRMAN LIEB: If there is no further discussion on the paper under consideration, we will proceed to the paper on "Insulating Materials in High-Tension Cables," by Mr. E. Jona of Italy.

Mr. Jona then read his paper.

INSULATING MATERIALS IN HIGH-TENSION CABLES.

BY E. JONA, *Delegate of Associazione Elettrotecnica Italiana.*

We have now in operation plants working at 50 to 60 kilovolts, with aerial lines. It is said that some will be installed at 80 kilovolts or even higher, but I do not believe there is any manufacturer ready to furnish cables for such high tension, although, of course, every manufacturer has occasionally had samples of cables tested as high as 100 kilovolts, without perforating them.

Let us take a glance at the conditions of manufacturing such very high-tension cables.

First, as to some theoretical difficulties. Let us suppose for the sake of simplicity, a single-core lead-covered cable with the following data: $r =$ radius of solid copper wire; $s =$ thickness of the insulation; $r + s = R$ external radius of the insulation. An alternating current is flowing through the cable, at a tension V. In the limits of ordinary frequencies, we can speak of potential, and use the electrostatic laws in any section whatever of the cable. The potential at a point P (Fig. 1) at a distance ρ from the center will be then:

$$v = V\frac{\log\frac{R}{\rho}}{\log\frac{R}{r}} \qquad (1)$$

Differentiate (1) with respect to ρ, taking decimal logarithms, and we get:

$$\frac{dv}{d\rho} = \frac{0.434\,V}{\rho\log\frac{R}{r}} \qquad (2)$$

$\frac{dv}{d\rho}$ is the gradient of the potential, or its variation along the radius. If we refer the dielectric strength of materials to the millimeter as unit of thickness (and assume for example that a given material can stand 10,000 volts per mm thickness) and

express our formula in mm, $\frac{d\,v}{d\,\rho}$ will be the puncture stress on the dielectric per mm, at the point considered. It must be less than the dielectric strength in order not to have a break-down;

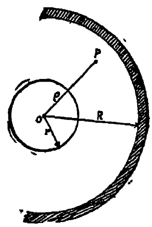


FIG. 1.

in our example, it must always be less than 10,000 volts per millimeter.

In the formula (2) putting $r = \rho$ we have

$$\left(\frac{dv}{d\rho}\right)_r = \frac{0.434\,V}{r \log \frac{R}{r}} \dots\dots\dots\dots\dots\dots\dots\dots (3)$$

This is the stress on the small dielectric layer immediately surrounding the inner conductor. For $\rho = \mathrm{R}$

$$\left(\frac{dv}{d\rho}\right)_R = \frac{0.434\,V}{R \log \frac{R}{r}} \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

the stress on the small dielectric layer near the outer lead.

It is to be remarked that the stress is greatest in contact with the conductor, and minimum in contact with the outer lead; and the latter is precisely equal to the former multiplied by $\frac{r}{R}$. r is generally very small in high-tension cables, and R very large. There is thus a very great difference in the stress on the different small dielectric layers, the most internal of which must support a tension three, four, five times that of the external layer.

There is a certain value of r for which the maximum stress $\left(\frac{dv}{d\rho}\right)_r$ is as small as possible, for a given R; we obtain this value of r by equating to zero the derivate of $r \log \frac{R}{r}$ with respect to r. Hence we have:

$$r = \frac{R}{\epsilon} = \frac{R}{2.71} \dots\dots\dots\dots\dots\dots\dots\dots (5)$$

I shall consider later the very frequent case where the conductor is not a solid wire, but a stranded one, and the relative formulas for any stranded conductor.

These brief considerations point to the conclusion that doubling the thickness of the dielectric by no means allows of doubling the dielectric stress on the cable; for the strength increases much less than the increase of thickness. Practically, for the sake of manufacturing, handling, etc., we cannot use too great thicknesses, especially if we consider also the weight of lead and armoring. If we admit that a homogeneous dielectric in a cable is punctured as soon as the stress surpasses in some point the dielectric strength, we see immediately the enormous advantage of using materials of very high specific strength. In fact, if we can with safety allow the material to be worked at w volts per mm, the formula (3) gives us immediately the thickness required.

$$w = \frac{0.434\, V}{r \log \frac{R}{r}} \quad \text{whence } \log R = 0.434\, \frac{V}{rw} - \log r \ldots\ldots\ldots\ldots (6)$$

This formula tells us that R diminishes rapidly by augmenting w.

A numerical example will illustrate this better. Let $r = 10$ mm and $V = 20{,}000$ volts; and suppose we have at our disposal an insulating material able to stand 12,000 volts per mm and another for only 8000 volts per mm. Let us take the same factor of safety, say one-fourth, in both cases; that is, we work at a maximum of 3000 volts per mm for the former, and 2000 volts for the latter.

In the first case we ought to have a thickness of 9.45 mm and in the second 17.20 mm. The volumes of the insulation are respectively 875 mm^3, and 2000 mm^3; they are in the ratio of 1 to 2.28 whilst the ratio of the dielectric strengths is as 1: 1.5. In this example the volumes of the insulation vary almost inversely as the squares of the dielectric strength.

In a 40,000-volt cable, with $r = 10$, and $w = 3000$ V per mm, we ought to have an insulating thickness of 66 mm; that is, a thickness impossible in practice. We see that, in this case, doubling the working tension compels us, *cæteris-paribus,* to use seven times the previous thickness. Hence it is obvious that it is not possible to manufacture 40,000-volts cables, with a material working with safety only to 3000 volts per mm.

Two insulating materials are now principally competing in the field of high-tension cables — vulcanised rubber and paper im-

pregnated with rosin and oil mixtures. Both have their partisans and their opponents. Paper insulation has made great progress in the last few years. The utility of using good manilla paper, laid on in thin and regular layers, without wrinkles and crumpling, has been recognized, and also the utility of having it properly dessicated, at a moderate temperature, in a vacuum, and impregnated with a compound of rosin, or wax, or asphalt, with mineral, or castor, or linseed, or some other oil, that does not become brittle or pulverise with age. But rubber also has made progress; and if some feared formerly that it could decay with age, it is now certain that first-class rubber cables, well vulcanised and removed from the influence of brush discharges in the air, or not alternately dry and wet, will last indefinitely.

Rubber has a dielectric strength much higher than impregnated paper. Testing good rubber cables in such lengths as to include the inevitable irregularities of manufacture, with tensions progressively increasing and subjected to dielectric strain at least one hour, we can easily obtain for the rubber a dielectric strength of 12–15 kilovolts per mm. Paper in the same conditions would only stand 8–10 kilovolts per mm. These numbers represent as good an average as we can reach in normal manufacturing; it is not rare to find 20–30 per cent more, or even higher percentages, but we cannot reckon upon these. The higher dielectric strength of rubber brings us to the conclusion that the use of rubber for very high tension will extend more and more.

A cause of inferiority of the rubber is the lesser homogeneity of its products. It is not uncommon to find that two cables manufactured in the same manner, with the same quality of rubber, afford a very different resistance to perforation — a difference, say, of 30–40–50 per cent. Paper cables are more homogeneous. The figures relative to dielectric strength given above are the result of a great number of tests made by the author on cables of various makers. They do not take account of some exceptionally high strengths; I found some pieces of rubber cable to withstand 20–25 kilovolts per mm. The elasticity of rubber gives it a great superiority over paper. A paper cable with large thickness of paper cannot be easily bent, especially in cold weather, owing to cracking; on the other hand, the manufacture of concentric, or stranded, multiple-core cables is simpler in the case of paper cables, for the insulating material can be uniformly distributed in the interspaces

among the conductors, which remain buried in the insulator. This is not possible with rubber.

The great success of paper cables is a consequence of their lower price. But very high tensions require such a greater thickness of paper, that the cost of the paper added to the extra price for the larger quantity of lead, steel, tape, etc., permits the rubber to win in the competition.

The problem of manufacturing high-tension cables would be simpler if the gradient of the potential within the body of the insulator was constant. Suppose a 38-mm^2 cable insulated to 14.5 mm outer radius, and working at 25,000 *V*. The layer near the copper supports a strain of 5,000 volts per mm, while near the lead the stress is only 1200 volts per mm. Should the stress be constant throughout, each layer of 1 mm would support a strain of 2270 volts, and the cable would be much safer. We could then also diminish the thickness of the insulation to, say, 5 mm, letting every layer work at 5000 volts.

This ideal condition of uniform gradient we can seek to reach in practice. A similar proposal was made by Mr. O'Gorman in a highly interesting paper, read before the I. E. E. London, on March, 1901; but it is difficult to imagine how Mr. O'Gorman's system can be practically applied. It consists chiefly in embedding the layers of paper more or less in some oils (like castor oil) according to their distances from the center; so that the inductive capacity of any layer is in inverse ratio to these distances.

Without claiming to get an absolutely constant gradient, we can, therefore, try to have the potential better distributed along the radius of the insulation, and at the same time use in the proper place materials having greater dielectric strength, by making the insulating layers of different materials specially chosen. This method I studied and applied to the manufacture of high-tension cables, as early as 1898. Such cables, consisting of conductors first insulated with several layers of rubber, on which were wound layers of paper or jute, were patented by Messrs. Pirelli & Company, March, 1900. A cable of this kind was working at 25,000 volts, during the Paris Exhibition of 1900.

The specific inductive capacity of paper cables varies from 3 to 4, according to the type of paper and mixture adopted. The inductive capacity of paper is about 2; that of rosin 2 to 3, according to its origin; and mixtures of rosin, oil, paraffin, ozokerite,

and other materials, have a capacity 3 to 4, or even more. For example, lubricating oil 55 parts, rosin 560, paraffine 224, ozokerite 160, have a s.i. capacity of 3.6; oxydized linseed oil 90, rosin 370, Arkangel pitch 70, have 4.4; Arkangel pitch itself has 5.9; a mixture with Gallipot, instead of rosin — for example Gallipot 600, Arkangel pitch 110 and linseed oil 130 — have 4.8; a mixture of lubricating oil 9, rosin 52, black ozokerite 23, white ozokerite 16, have only 3.55.

It appears from these figures that it is possible to have a large range of inductive capacity with paper cables. But as they are impregnated in mass, the entire mass has the same s.i.c. unless we change the type of paper, by using, for example, paper loaded with some materials, as suggested very ingeniously by Mr. O'Gorman; but I do not know if he succeeded in doing so. On the contrary, it is easy to use different rubbers having very varied s.i.c., for rubber is put on in successive layers which can be quite different one from another, and which have no tendency to mingle together, either during or after manufacture. The cables I alluded to are manufactured with layers of various qualities of rubber in the inner part of the insulation; but as soon as the gradient of potential becomes so diminished as to allow the use of paper, the insulation is continued with paper, and after the paper with jute, if the gradient is sufficiently low to allow the use of jute. The rubber insulation is generally first vulcanized and the conductor tested in water, as usual, before adding the outer layers of paper and jute.

Pure vulcanised rubber has an inductive capacity something like 3 as an average; but it is very easy to "load" the rubber with large quantities of extraneous materials, which, without sensibly lessening its specific dielectric strength, augment the capacity very much. A rubber with 58 per cent para, 2 per cent sulphur, 26 per cent talc and 14 per cent oxide of zinc, has a dielectric strength comparable to that of pure vulcanized para (15–20 kilovolts per mm); and a specific inductive capacity of 4–4.2. A rubber with 64 per cent para, 8 per cent sulphur, 16 per cent talc, 8 per cent minium, 4 per cent oxide of zinc has about the same dielectric strength as above mentioned, while its specific capacity reaches 5. A rubber largely loaded with sulphur and talc, for example para 100, talc 40, and sulphur 40, has a capacity as high as 6.10, with a dielectric strength of the same order of magnitude as before. A mixture of para 40, carbonate of lime 55,

sulphur 5, has a s.i.c. of 4.6. Very large variations of capacity, accompanied by high dielectric strength, are obtained by loading rubber with more or less sulphur and golden sulphurate of antimony still remaining first-class rubber. Much larger capacities, 10–12, are to be obtained, of course, by using very large percentages of India rubber substitutes, and gypsum, lime, baryta, etc.; but we then arrive at inferior classes of rubber, which have not a dielectric strength to be compared with the above-mentioned combinations.

It is very easy to manufacture rubber cables with layers disposed in the order of decreased specific capacity, from the center to the circumference. These cables will afford a more uniform gradient to an alternating current, and hence more safety, with equal thickness. By using paper on the rubber, as above explained, we concentrate the more costly rubber insulation in the inmost part of the cable, where its higher specific strength is actually utilised.

A single-core cable made by this method for 50 kilovolts effective tension, between the copper and the outer sheathing, has the following specifications: Conductor, 19-wire strand, each wire 3.3 mm diameter; section of copper 162 sq. mms. The strand is put in a lead tube having 18 mm outer diameter. It is insulated with a first layer of rubber, 2.5 mm thick, having a specific inductive capacity of 6.1; then with a second and a third layer of rubber of respectively 2.3 and 4.5 mm thick and 4.7–4.2 s.i.c. On the rubber there is a layer of impregnated paper 5.2 mm thick, having an s.i.c. of 4. The cable is then lead covered. The total thickness of insulation is 14.5 mm.

At 50,000 volts, the maximum strain in the first layer of rubber is 4400 volts per mm; in the second layer it is 4450 volts, in the third 4150 volts and in the paper 3250 volts per mm. With a homogeneous dielectric, the maximum strain would be 5800 volts. This cable was tested for one hour at each of the following voltages; 35,000 effective volts, 40,000, 45,000, 50,000, 55,000, 60,000, 65,000, 70,000, 75,000, 80,000, 85,000, 90,000, 95,000 and four hours at 100,000 volts without perforation. After the 80,000 volts test, its temperature was a few degrees higher than that of the room; and after four hours at 100,000 volts, 20 deg. C. higher.[1]

1. In order to have the same maximum stress of 4400 volts with a homogeneous dielectric, the thickness ought to be 23.04 mm; the outside radius would be 32 mm and the total volume of insulation would be doubled.

The distribution of the potential in such a cable is easily calculated. Suppose between the conductor A (Fig. 2) and the lead B, a number n of cylindrical rings possessing respectively a dielectric constant ε_h where h varies from 1 to n; the ring ε_h is limited by the radius r_{h-1} and r_h; let V be the total voltage. The potential at a point P at a distance ρ_h in the compartment ε_h is given by:

$$v = \frac{V\left(\frac{1}{\varepsilon_h}\log\frac{r_h}{\rho} + \frac{1}{\varepsilon_{h+1}}\log\frac{r_{h+1}}{r_h} + \cdots\cdots + \frac{1}{\varepsilon_n}\log\frac{r_n}{r_{n-1}}\right)}{\frac{1}{\varepsilon_1}\log\frac{r_1}{r_0} + \frac{1}{\varepsilon_2}\log\frac{r_2}{r_1} + \cdots\cdots + \frac{1}{\varepsilon_n}\log\frac{r_n}{r_{n-1}}} \qquad \text{....(7)}$$

which, for a single homogeneous insulation becomes $v = V\dfrac{\log\frac{R}{\rho}}{\log\frac{R}{r_0}}$, as before.

The above considerations have a somewhat too theoretical appearance, and it is convenient to have them submitted to the test of

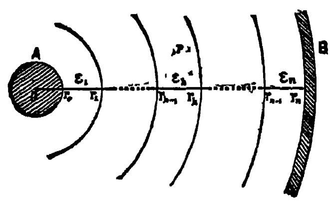


FIG. 2.

experiment. As for the distribution of potential along a radius of insulation, there can be no doubt; and experience confirms it perfectly. Experiment confirms also the distribution in an heterogeneous dielectric, taking into account the various specific inductive capacities of the layers. But experiment gives some unexpected results when we consider the perforation of the cable. The system I follow is to attach the cable to a large transformer, the potential of which is gradually raised until the cable is perforated; but any potential is applied to the cable for one hour or more, before raising it. It is then also possible to note the heating of the cable for hysteresis or conductivity. The short piece perforated is then cut off, and a test is applied to the remainder, raising the potential until a new perforation, and so on. The first thing to be noted is that results are not uniform. A length of cable

begins, for example, to be perforated at 10,000 volts, but the following perforations require 12–15 and more kilovolts. That means that our dielectrics are not homogeneous, while perfect homogeneity is presupposed in our formulæ. Another experimental fact is the following: Let us insulate a copper wire of 1/10 mm diameter, with 7 mm thickness of rubber, and, in the same manner, a strand of 70 wires, each of 0.25 mm with the same thickness of 7 mm; the former will be perforated at 10,000 volts, the latter at 22,000. The latter is a thicker conductor, and our formula shows that a thicker conductor supports more stress with the same thickness of insulation. But if we calculate with our formula the maximum specific stress in contact with the conductor — that is to say the stress which we think will cause a perforation — we find it to be 12 kilovolts per mm for the thicker conductor, and 32 for the thinner one. Similarly, I have insulated with the same thickness of 14 mm of paper, a conductor of 1 mm and another of 29 mm; the former, after one hour at 30,000 volts, was very hot and burnt at 40,000, the latter, after one hour at 50,000 volts, was still cold and burnt at 75–80 kilovolts. The maximum specific strain calculated is 10,000 volts for the thicker, and 23,500 volts for the thinner conductor. These strains of 23,500 volts per mm for the paper and 32,000 volts per mm for the rubber, are abnormally high; and the higher specific dielectric strength (apparent or real, I do not know which) that I always observed in thin insulated wires, shows that some other phenomenon exists in the dielectric.

Our formula, perhaps, lacks recognition of the mutual action of the different dielectric layers. We imagine the dielectric divided into concentric rings, for which we calculate the strain; and if it surpasses the dielectric rigidity we have assigned to the dielectric, we say that it will be perforated. Each ring is not influenced by the others, according to this manner of viewing the phenomenon, except for the distribution of potential; afterward it is considered as neither helped by nor helps the others. That is, perhaps, too statical a conception; dynamical influences are not considered here, but perforation is dynamical. It requires a certain amount of energy, which is spent not only in the first layer we have considered, but also in the others. The layers cannot then be absolutely independent. Let us take, for example, a sort of concentric cable, the inner conductor made with a copper wire 4 mm thick, insulated with jute to 8 mm; on the jute, a thin brass tape

represents the outer conductor, insulated with a layer of 3 mm vulcanised rubber; the cable is then drawn into a lead pipe. Apply an 8000-volt transformer between the inner conductor and the lead, leaving the brass tape insulated. At this tension the jute is perforated, between the copper and the brass tape; the jute is thus put out of service, and the total tension is brought on the rubber, which supports it very well. If we calculate the initial distribution of the potential, we see that the strain on the jute was 3300 volts, which is too much for this kind of insulation, which will burn. The layer of rubber cannot give any help to jute in this condition, for brass tape separates it from jute.

But if we make a cable absolutely like this, but without the brass tape, the phenomena are quite different. No doubt the distribution of potential and the gradient are unchanged. Let us put in circuit an electrodynamometer to measure the capacity current, and we shall have the following readings at the respective tensions:

Volts	5000	7000	9000	11,000	13,000	15,000
Deflection	33	62	105	150	220	297

The deflections are in the ratio of the squares of the tensions, whence we deduce that the capacity of the cable remained unaltered, under current, after many hours testing, at potentials much higher than before. If the jute was perforated, burnt, or carbonized, the capacity ought to have increased, and the deflections would have increased more than according to a simple square law.

This mutual aid explains why it is possible to mix together very different materials and get good dielectrics. For example, there are the various mixtures of rubber, or the micanite insulations, where many layers of different capacity and strength, such as paper, mica, shellac are wrapped alternately. But if we exaggerate, we shall end by burning the weakest dielectric layers, without perforating all the cable, which still continues to work.

Such a phenomenon occurs in dielectrics, especially when of organic matters, which are never homogeneous. By testing them at too high tensions, as required by some engineers, we may destroy the more strained and weaker particles of the dielectric, without immediately perceiving it. We have thus an idea of the reason opposing too severe voltage testings, which may produce deterioration in the dielectric.

If we calculate with our formulæ the thickness required to insulate for 50,000 volts, a wire of 0.1 mm diameter, assuming

we allow the dielectric to work at 4000 volts per mm, we find a number which can be expressed in millions of kilometers better than in millimeters. Such a bare wire suspended by insulators in air can effectively transport energy at 50,000 volts, although air has, of course, much less dielectric strength than rubber. But if we observe the wire in the darkness, we remark that it becomes illuminated. It is surrounded by a very vivid brush discharge, and the wire has the appearance of a uniform cylinder of light of great diameter. We can consider that air has become a conductor, as regards the distribution of the potential, to the limit of the brush discharge; and we have no longer a conductor of 0.1 mm diameter, but one having the diameter of the brush discharge. Even if we suppose this latter to be only 5–6 mm, the millions of kilometers are reduced to two meters. That is, a wire of 0.1 mm suspended in the air, two meters from the earth, will be the seat of a brush discharge having an apparent diameter of 5--6 mm when brought to 50,000 volts, if we suppose air has a dielectric strength of 4000 volts per mm.

Such a phenomenon can, perhaps, occur in solid dielectrics, when the conductor is very thin; perhaps the very first layers of insulation become conductors as regards the distribution of the potential. This may explain the higher dielectric strain supported by very thin insulated wires to which I referred above. This fact can, perhaps, be explained also by a deficiency of adherence between the dielectric and such a thin conductor; or, perhaps, by some particular phenomenon on the surface of separation between conductor and dielectric, of which we have many examples in other branches of physics.

The influence of the diameter of the conductor on the total strength of a cable can be very well placed in evidence by taking air as an insulator. If we have an aerial line on insulators, 1½ meters from the earth, with wires of different diameter, say from 0.12 to 15 mm, and attach this line to one pole of a transformer, the other pole of which is attached to an insulated distant line, we remark that at a total tension on the transformer of 12,000 volts, only the 0.120-mm wire commences to show brush discharges, and that this phenomenon appears only at 185,000 volts with a 12-mm wire, while at 196,000 volts the 15-mm wire does not yet show brush discharges. (Fig. 3.) Under tension, all the wires examined in the darkness appear to have about the same diameter, which is the one that reduces the gradient below the dielectric strength of the air.

Air is a good dielectric for such researches, for we can see what happens in the dielectric. Thus, if we submit a solid wire and stranded or braided wire having all the same external size, to a very high potential, we do not see any great difference in the potential at which brush discharge commences. We can then foretell that the dielectric strength of a cable is not influenced very much

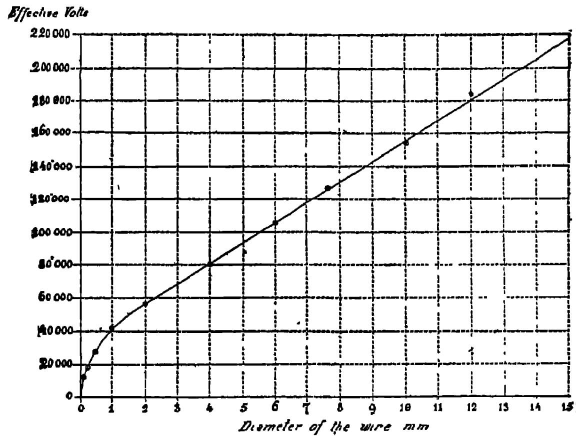


FIG. 3.— BRUSH DISCHARGE VOLTAGE FOR VARYING DIAMETERS.

by the shape of the conductor, if stranded or solid wire, at equal diameter. But it is a difficult matter to judge the phenomenon exactly by sight. I tried to take photographs at 2 meters distance with a lens of 1 meter focal distance; but photographs do not represent the phenomenon as we see it.

From another point of view, testing an insulated cable cannot give us a numerical value of the difference between a solid wire and a stranded conductor, because of the irregularities and heterogeneity of the dielectric. It would, therefore, be very useful to investigate the matter by mathematical analysis. In this very difficult problem I happily was able to interest Prof. Levi-Civita. It is not possible to examine here this complex theoretical study and I shall limit myself to a few words. Let us consider a stranded conductor, and let m be the number of the wires in the *external* layer of the strand, and R the radius of the insulation. Let r be the radius from the center of the strand to the points of contact of a wire of the external layer, with its neighbors (nodal point of the external wire layer). (Fig. 4.)

In a solid conductor of radius r insulated to a radius R, we have seen (formula 3) that the maximum gradient for a potential equals to unity is

$$G_1 = \frac{1}{r \log_\varepsilon \frac{R}{r}}.$$

In the strand with m wires in the external layer, we shall have:

$$G = G_1 \frac{\varepsilon^{-\mu}}{1 - \mu r G_1} F^2 \left(\frac{1}{2}, \frac{1}{2}, 1 + \frac{1}{m}, \frac{1}{2}\right) \ldots\ldots\ldots\ldots\ldots \text{(10)}$$

$$\text{where } \mu = \frac{4}{m} \log_\varepsilon 2 + 4 \sum_{v=1}^{v=\infty} \frac{S_{2v+1}}{2v+1} \cdot \frac{2^{2v} - 1}{m^{2v+1}} \ldots\ldots \text{(11)}$$

and $s_3 = 1.2020 \quad s_5 = 1.0369$, etc.

are the sums of the inverse of the third, fifth, etc. powers of integer numbers; and F is the symbol of the hypergeometrical series of Gauss.

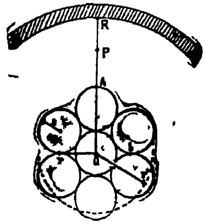


FIG. 4.

These formulas allow one to calculate the gradient, but it is well to compare the gradient of a strand to that of a solid wire of the same section. Practically the total number of the wires in a regular strand, having m wires in the external layer, is given by

$$N = 1 + \frac{m(m+6)}{12}$$

and the radius of a single wire is $a = r \tan \frac{\pi}{m}$, all the wires of the strand having the same radius a.

Let r' be the radius of a solid wire having the same section as the strand: then

$$r' = r\sqrt{N} \tan \frac{\pi}{m} = r\varepsilon^{a}$$

Where $\varepsilon^{e} = \sqrt{N} \tan \frac{\pi}{m}$. The formula (10) becomes (taking decimal logarithms)

$$G = G' \varepsilon^{-(\mu - e)} \frac{\log_{10} \frac{R}{r'}}{\log_{10} \frac{R}{r'} - (\mu - e) \times 0.434} F^2 \left(\frac{1}{2}, \frac{1}{2}, 1 + \frac{1}{m}, \frac{1}{2} \right) \qquad (12)$$

where $G' = \frac{0.434}{r' \log_{10} \frac{R}{r}}$ represents the maximum stress in a solid wire cable having the same R and the same section (for a potential equal to unity.)

With a stranded conductor, the condition of maximum safety for a given R is

$$r = \frac{R}{\varepsilon \times 2^{\frac{4}{m}}} \qquad (13)$$

or putting the radius r' in evidence as before

$$r' = \frac{R}{\varepsilon^{1 + \mu - e}} \qquad (14)$$

If we keep R and m constant and we vary a, the thickness of the elementary wire, the value of G given by the formula (12) increases when $r' > \frac{R}{\varepsilon^{1 + \mu - e}}$ and diminishes in the contrary case.

If we keep constant the diameter of the insulation and the section of the conductor, the maximum strain, G, increases with m; but the term $F^2 \varepsilon^{-(\mu - e)}$ has for $m = 6$ the value of 1.232, and for $m = \infty$ the value 1.258. They do not differ very much, and, for safety, we can assume $F^2 \varepsilon^{-(\mu - e)} = 1.26$. The value of 0.434 $(\mu - e)$ varies from 0.026 for $m = 6$, to 0.042 for $m = \infty$ and we can, for safety, assume it to be constant and $= 0.042$. Then formula (12) becomes:

$$G = 1.26\ G' \frac{\log_{10} \frac{R}{r'}}{\log_{10} \frac{R}{r'} - 0.042} \qquad (15$$

The discussion of the formulas brings us to the conclusion that the ratio $\frac{G}{G'}$ — that is the augmentation of the maximum stress in a stranded conductor with respect to a solid wire of the same section — varies between the limits 1.232 and 1.462. The former cor-

responds to $m=6$ with a very large thickness of dielectric; the latter corresponds to $m=\infty$ and $\frac{R}{r'}=2$ — that is to a thickness of dielectric very small in practice. In the most favorable case, the ratio being 1.232, it is advisable not to use stranded conductors for very high-tension cables, but to cover the strand with lead sheathing.

We may observe that for $m=\infty$, the gradient tends toward its highest value — higher than with a solid wire inscribed or circumscribed with respect to m. This is not so strange, for the value of G affects only the small layer near the conductor, and however great m may be, we shall always have an external layer of small circles, having $G=O$ at the nodal points b of the external wires, and G a maximum at the *loop* points A. (Fig. 4.) This is true from a mathematical point of view; but, physically, we have some compensation between the maximum and the minimum, which will bring the value of the coefficient to unity; that is, physically, we shall have for a very great m the same value as with a solid wire.[1]

Experience confirms these deductions. I took a cable whose conductor was partially a solid wire 7 mm in diameter; partially

1. From Prof. Levi-Civita's formulas we can compare the capacity of a solid wire r' insulated to R with the capacity of a stranded conductor of equal section, insulated to R. r being, as usual, the radius of the knot-points of the strand, the capacity of the strand is

$$C_m = \frac{x}{2}\,\frac{1}{\log_\varepsilon \frac{R}{r} - \mu} \qquad \ldots\ldots\ldots\ldots(16)$$

where x is the specific inductive capacity. This formula is true also for an irregular strand; for example, a thick copper wire, surrounded by a number m of smaller wires, as used in some submarine cables.

Introducing the conception of the solid wire of equal section we have, taking decimal logarithms:

$$C_m = \frac{x}{2}\,\frac{0.434}{\log_{10}\frac{R}{r'} - 0.434\,(\mu - e)} \qquad \ldots\ldots\ldots\ldots(17);$$

while for the solid wire cable we have:

$$C = \frac{x}{2}\,\frac{0.434}{\log_{10}\frac{R}{r'}}.$$

As $\mu - e$ is always positive and increases with m, we conclude that $C_m > C$ and increases with m. At the limit, for $m=\infty$

$$C_\infty = \frac{x}{2}\,\frac{0\ 434}{\log_{10}\frac{R}{r'} - 0.042} = \frac{x}{2}\,\frac{0.434}{\log_{10}\frac{R}{r}}.$$

Generally, the thickness of the insulation is greater than the radius of the conductor and therefore $\log_{10}\frac{R}{r'}$ is generally $> \log_{10} 2 = 0.301$; therefore the increase of the capacity attains practically only a very small percentage.

strands of 7×2.34 mm, and 19×1.4 mm; and partially a solid wire of 6 mm surrounded by 40 thin wires of 0.5 mm diameter. They were all insulated with 5 mm thickness of jute. If we calculate the maximum strain per mm by our formulas, we find that it is 0.32 of the total tension in the solid wire, 0.418 in the 7-wire strand, 0.424 in the 19-wire strand, and 0.432 in the strand having an external layer of 40 thin wires.

During the tests the 19-wire strand began to burn at 17,000 volts, and successively at 18–21–23–25 kilovolts; the 7-strand wire was first perforated at 19,000 volts, and successively at 20–22–24–25 kilovolts; the strand of 40 thin wires began to be perforated at 29 kilovolts, and afterward it experienced many other punctures from 29,000 to 33,000 volts. The first puncture in the solid wire was at 28,000 volts, probably a weak point, for the successive punctures were from 32 to 38 kilovolts.

It is evident that the heterogeneity of the dielectric does not allow us to deduce any numerical law from these tests, but the general conclusion is that the solid wire is the strongest, and the 7-wire strand is very little stronger than the 19-wire strand. That is in accordance with theory, but the strand of 40 thin wires ought to be the weakest of all, according to pure theory; whereas though less strong than solid wire, it is stronger than the other strands. But as I remarked above, theory points to a maximum strain for $m = \infty$. while $m = \infty$ is physically equal to a solid wire; and we must admit that, in the case of $m = 40$, the physical average which we alluded to commences to have a great influence on the result.

Of course theory cannot foretell such complex phenomena. First of all, theory considers dielectrics perfectly homogeneous; and, secondly, it cannot take into account the mutual aid of the neighboring layers, or molecules, which tends to equalize the gradient in any elementary zone. We must then be very careful in applying the results of theory. Theory must be for us like a lighthouse for sailors; we can use it to direct our course, but we do not depend upon it indefinitely to save us from wreck. For example, we found that with a given R, the maximum safety is obtained by taking $r = \frac{R}{\varepsilon}$. High-tension cables have generally r smaller than the above ratio. After having calculated R, we might be tempted to augment r till that ratio was reached, as well as in the case where this thicker r is useless to carry the current; or we could imagine making the conductor of aluminum, thicker and more economical.

But we should not forget that the heterogeneity of dielectric would cause this to be dangerous; with an impurity present we have a smaller range of thickness to rely upon, and the cable would then break down. We can, of course, augment r a little, but less than theory indicates. I have followed this practice for some time with very high-tension cables; the wire strand is covered with a lead tube, which augments its diameter. The lead has also the advantage of rendering the conductor round, and of preserving rubber from contact with copper in rubber cables, or in cables whose insulation is composed of rubber and paper, as I have explained above.

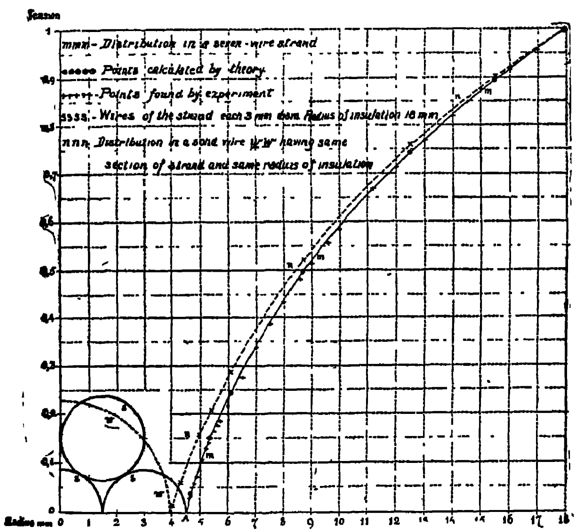


FIG. 5.—POTENTIALS AT SUCCESSIVE RADII.

It is said that a manufacturer has found it advantageous to surround the stranded conductor with a layer of thin wires, (say 1.4 mm in diameter) separately wrapped with a small thickness of paper; these wires are connected with the strand, so that no difference of potential exists between the strand and the wires. It is said that a gain of 20–25 per cent was thus found in the dielectric strength of the cable. I have not a large experience with such a type of cable, but some experiments I have made do not point to an advantage, and it would be difficult to explain why there should be an advantage with this type; the small wires of the external layer become separated one from the other, so that equipotential lines must bend very much. If the advantage really exists, perhaps it is to be attributed to the larger specific dielectric strength of thin insulated wires, to which

I referred above, but in this case, would it not be better to use an external layer of thinner wires, laid on contiguously, without any special insulation on each wire? Some experiments which I have made seem to point that way.

We can also test the theory by calculating the value of potential along a radius, and checking it in an experimental or model cable obtained by soldering a strand conductor and a ring upon a thin metallic sheet, and letting a current flow in the sheet from the strand to the ring. Potentials can thus be easily measured. Fig. 5 shows the theoretical curve and the experimental one, which are very much alike.[2]

The above considerations allow us to calculate single-core cables. Three-phase cables can be calculated by considering one conductor

2. This theoretical curve $\rho = f\ (v)$ is obtained from the following formulæ where v is the potential, whose value is zero in the inner conductor and 1 in the lead sheathing. r, R, μ, F have the meanings I have already explained: It is to be remembered that $F\ (\alpha, \beta, \gamma, x)$ is the symbol of the hypergeometrical series of Gauss.

$$1+\frac{\alpha}{1}\frac{\beta}{\gamma}x+\frac{\alpha\ (\alpha+1)}{1.2}\frac{\beta\ (\beta+1)}{\gamma\ (\gamma+1)}x^2+\frac{\alpha(\alpha+1)(\alpha+2)}{1.2.3}\frac{\beta(\beta+1)(\beta+2)}{\gamma(\gamma+1)\ (\gamma+2)}x^3+\cdots\cdots\cdots$$

ρ is the radius of the point P taken along a radius $O\ A$ passing to a loop point A; (Fig. 4) the potential at P has the value v.

Putting $s_1 = \varepsilon^{m\,\mu}.\left(\frac{r}{R}\right)^m \quad s = \frac{s_1^v}{1+s_1^v}$, we have:

$$\rho = r\ \left(\frac{R}{r}\right)^v.\varepsilon^{\mu(1-v)}.\frac{F\,(\frac{1}{2},\ \frac{1}{2},\ 1-\frac{1}{m},\ s)}{F\,(\frac{1}{2},\ \frac{1}{2},\ 1+\frac{1}{m},\ s)}.$$

The experimental curve was obtained in a model made to a scale $\frac{10}{1}$; the conductor is a 7-wire strand, each of 3 mm diameter (30 mm in the model) insulated to a radius $R = 18$ mm (180 mm in the model).

Values of	In a strand of			
	7 wires, $m=6$.	19 wires, $m=12$.	37 wires, $m=18$	$m=\infty$.
$F^2\ (\frac{1}{2}, \frac{1}{2}, 1+\frac{1}{m}, \frac{1}{2})$	1.31	1.34	1.35	1.39
μ	0.484	0 282	0.157	0
$\varepsilon^{-\mu}$	0.615	0.794	0.854	1
$\varepsilon^{-\mu}.\ F^2$	0.826	1.05	1.152	1.39
$\frac{r}{a}$	1.732	3.732	5 67	....
$0.484\ (\mu-e)$	0.026	0.034	0.036	0.042
$\varepsilon^{\mu-e}$	1.062	1 081	1 087	1.107

at a potential, of say, $\frac{V}{\sqrt{3}}$ volts; we get then the radius of the insulation around each conductor. We can consider afterward the same conductor to be insulated for V volts; we get then the distance between the center of this conductor and the lead, and, therefore, the thickness of the extra insulator around the strand of the three insulated cores. The factor of safety for this extra insulation need not absolutely be the same as for the former, as it corresponds to an abnormal case of a phase break-down. Compound cables, with rubber, paper and jute, are calculated according to the respective dielectric strengths of these materials, distributed in the depth of the dielectric, according to the radial gradient.

Gutta-percha possesses also very great dielectric strength, comparable to that of good rubber, 15–20 kilovolts per mm. It is not used for insulating cables for lighting or power purposes, because of its very high price, and especially from its low melting point. Such cables can easily reach a temperature which softens gutta-percha. A possible application of gutta-percha is for cables crossing lakes, rivers, and, generally speaking, for laying in cold water. It is then advisable to make a first layer of rubber insulation, on which gutta-percha is laid so that the latter, being in contact with external cold water, cannot heat very much. Many manufacturers do not trust the impermeability of rubber cables, and this external coat of gutta-percha, absolutely waterproof, adds its own dielectric strength to that of rubber and obviates the inconvenience of having a heavy lead pipe, as employed by the manufacturers to which I have alluded. It is often advisable in such cables to avoid splices, and for the sake of facility of transport and laying, they can be single-cored, rather than three-cored. I may add that single-core cables for very high tensions, requiring generally a low current strength, can often be armored with steel wires; the steel wires can be separately wrapped with tarred manilla, in order to lessen the section of the metal and increase the magnetic and electric resistance of the cross-circuit. For example, a 2.5-mm steel wire wrapped to 5–6 mm with manilla, may be used without any great inconvenience from hysteresis or self-induction; the drop of pressure by self-induction can have in such cables no more importance than the drop by ohmic resistance.

I would like to add something on the properties of various insulating materials, but I fear I have already passed the limit set for

papers. I shall, therefore, only say that these materials are influenced by Röntgen rays, which lessen their specific insulation and perhaps also their dielectric strength. But cables are not made to be submitted to such rays, although they often experience brush discharges and some other emanations, which may have similar influences. I should like to add that temperature lessens the resistance of the insulation very quickly, as expressed in megohms. A paper cable at 35 deg. C. shows but one-thirtieth of the megohms it has at 15 deg. C. But temperature has very little influence upon strength to resist breakdown. Palm oil melted at 50 deg. C. gives a strength corresponding to that of the best oils for transformers at ordinary temperature. I have drawn experimental curves of dielectric strength of melted paraffine at 55 deg. C. and at 85 deg. C. from 10 up to 160 kilovolts; they are very similar. This allows us to conclude that in this respect cables cannot differ very much. I have tested two reels of paper cables, each cut in 5 pieces, immersed in baths at 0 deg., 15 deg., 35 deg., 70 deg. and 100 deg. C. The dielectric strength did not lessen by raising temperature, perhaps at 0 deg. it was less than at 70 deg. I noted in some oils something similar, but dielectric strength is too complex a phenomenon to be discussed on small experimental differences. Of course, that cannot justify us in working at high tensions with cables too much heated, for it is probable that heat would facilitate a chemical decay of the dielectric; but a momentary elevation of temperature is not so much to be feared as one would think at first sight.

In conclusion I may say that the above considerations can be applied to some other matters. They explain, for example, the brush discharges between the petticoats of insulators. An insulator with many petticoats can be considered like a system of condensers in series; a large part of the tension is taken by air, which has 3 to 4 times less specific inductive capacity. They explain the "digestion" of the wooden pins with iron cores, in the insulators; for the gradient is greatest in the pins, and they become carbonised with age. They explain also the phenomenon that insulators tested with pins stand less than when tested with water, for water offers a larger and smoother surface. They explain the brush discharge at the surface of an insulated wire, drawn into a metallic pipe (for example in crossing a wall), for we have added in this case an external layer of air to the solid insulation; but air has a low s.i.c., and, therefore, it absorbs much tension, with a too

large gradient. In a similar manner we can explain the brush discharges at alternators, during very high-tension tests. These considerations explain also why the alternator coils separately wound, and wrapped with alternate layers of tapes and varnishes, are generally perforated in a corner of the coil, or corresponding to an external corner of the conductor, for there is here a higher gradient. They suggest some improvements in the construction of insulated coils for alternators, for example, by increasing the radius of curvature of the bunch of conductors,[3] or, by employing in the innermost part of the insulation some material like mica, which has the highest s.i.c., together with the highest dielectric strength against puncture. In short, they explain many facts which have been observed in practice.

Discussion.

CHAIRMAN LIEB: We have just listened to an excellent paper. It throws considerable light on a subject in which every central-station man, engaged in high-tension transmission, should have the greatest interest. The question of the quality of the dielectric, whether of paper or of rubber, is of great interest, and in this paper we have some suggestion as to combining the two so as to take advantage of the desirable qualities of each. The paper is now open for discussion.

Col. R. E. B. CROMPTON: I must congratulate this section on having before it the best paper on this subject that I have ever hitherto read. I think that Signor Jona deserves our most heartfelt thanks. He has compressed into it a large amount of study, not only of his own, but also of other peoples' practice, and he has concentrated into his last paragraph matter which is of such great importance not only to cablemakers, but to all of us who construct high-tension apparatus, that I believe his paper will be profitably studied by all of us.

Mr. Jona has called attention to a paper on the same subject read before our English Institution by Mr. O'Gorman. I was present at that paper and there is no doubt that to him must be given a good deal of the credit for suggesting the idea of grading the insulation so as to get equal strain on the several concentric layers, and which idea appears now to have been carried out in practice by Mr. Jona. I believe Mr. Jona is right in pointing out that rubber insulation is likely to be turned to increased importance by being used as the dielectric layer nearest to the conductor. It is evident also that Mr. Jona has disposed of the question as to the influence which the form of the outside conductor itself has on the breakdown stresses.

Mr. ROBERT HAMMOND: I arise to second the remarks of Lieut.-Col. Crompton. I was one of those gentleman who visited Italy last year, and

3. This can be obtained in some cases by covering the bunch with a sheet of metal, cut to avoid eddy currents, before applying the external insulation.

it was a great regret to us that, when we visited the works of Pirelli & Company, in Milan, that Mr. Jona was not present. He was engaged elsewhere disseminating that knowledge which he does on these occasions so admirably. I have felt for years that we electrical engineers have given far too much attention to the generating side of the question and that this question of the proper treament of cables is one which has not received the attention to which it is entitled. It is fortunate for us that we have a gentleman of Mr. Jona's acquirements to consider such a subject for us; and it is a high pleasure to us all to have before us such an exceedingly valuable paper. If we had come to St. Louis for nothing else, we would have come for this paper.

CHAIRMAN LIEB: If there is no further discussion, I will call on Mr. Jona for any concluding remarks.

MR. JONA: I have no further observations to make, but desire to thank Col. Crompton and Mr. Hammond for their kind remarks, and the audience for their kind expression in the reception of the paper.

CHAIRMAN LIEB: I am sure we can all felicitate ourselves with having such a classic on the subject presented in our section. We will now listen to a paper on "Distributing Systems from the Standpoint of Theory and Practice" by Mr. Philip Torchio, of New York. As this is a long and exhaustive paper, which will require very mature thought and study in the consideration of the tables, and the line of investigation and deduction which Mr. Torchio has presented, I will ask him if he will kindly abstract the paper as far as practicable without in any way affecting the presentation of the paper as a whole.

Mr. Torchio presented his paper.

DISTRIBUTING SYSTEMS FROM THE STANDPOINT OF THEORY AND PRACTICE.

BY PHILIP TORCHIO.

Systems of distribution of electrical energy are classified into *direct systems,* which utilize directly, without transformation, the electricity furnished by the generating station; and *indirect systems,* which modify the intensity and potential of the current by means of secondary apparatus, such as transformers, storage batteries, etc.

The direct systems were the first to receive commercial application. They have been, and always are, adopted where the electrical energy generated is to be distributed in the immediate vicinity of the power station. The Edison system of distribution was the model of the direct systems. Since the beginning of the early eighties it was, however, a recognized fact that on account of the prohibitive cost of transmission to great distances the direct systems alone could not give the solution of the general problem of economical generation of large amounts of power at a central point and economical distribution to distributing centers covering large areas more or less distant from the station.

The conditions of the problem were, therefore, to generate and transmit power at high potential and in relatively small quantity of current, and utilize the received energy at low potentials in large quantity of current. One of the first solutions which were suggested was the use of direct-current high-tension transmission, feeding in series a number of electric storage batteries distributed at convenient points along the high-tension circuit. Each storage battery would, independently, supply current to the local installation lamps.

The limitations of this system were soon recognized, and its importance was lost when the alternating-current transformer was brought into the field.

We are indebted to an English company—"The National Company for Distribution of Electricity by Secondary Generators, Limited"—for the first public demonstration of the rational solu-

tion of the problem. The National Company, exploiting the inventions of Messrs. Gaulard and Gibbs, showed in 1884, at the Exhibition of Turin (Italy), a system consisting of a 30-hp, 2000-volt, 50-cycle, single-phase alternator, feeding a single wire transmission circuit 48 miles long, having connected in series at different points along its route a number of transformers of the Gaulard and Gibbs type, feeding at different voltage through their secondaries a variety of incandescent and arc lamps.

Gaulard and Gibbs, recognizing as important that an alternating-current transmitting system should be capable of transforming alternating into direct current, devised a high-efficiency direct-current auto-commutating machine, which was schematically a self-starting, single-phase, 50-cycle, rotary converter. Soon after the close of the Turin Exhibition of 1884, Messrs. Zipernowsky, Deri and Blathy developed the parallel type of transformer for connection in multiple arc, which was exhibited at the Budapest Exhibition of 1885.

The results obtained with the Gaulard and Gibbs transformers at the Turin Exhibition attracted the widest attention among engineers, and opened the way to classical laboratory researches and monumental discoveries in the field of application, which laid the foundation to all future developments. From this beginning it became apparent to the best engineers what was the line to follow in the development of the distribution of electrical energy.

To give an idea of the clear conception of the problem that these engineers had at the time, I do not think it would be amiss to quote the following abstract from an article by Prof. G. Colombo, published in *La Lumière Electrique,* of Oct. 11, 1884:

"* * *. The first impression made by this simple description of the system (the Gaulard and Gibbs system) is this: At present the problem of distribution for electric lighting is, we will not say definitely solved, but made easy in a large measure and made applicable to limits until now unattainable * * *."

Prof. Colombo then compares the relative cost of installation of an Edison underground system of distribution with an alternating-current, house-to-house, transformer system, and he arrives at the conclusion that the two systems would cost approximately the same. He also discusses the relative advantages of the two systems and draws the following conclusions:

"* * *. We are, therefore, brought to this dilemma: The Edison system of distribution cannot be supplied except within

the limits of a rather small radius; on the other hand, the Gaulard and Gibbs system does not present the same advantages that the Edison system does, not being as well adapted for distribution of electric light under the same conditions that water and gas are distributed. But isn't it precisely out of this dilemma that we must look for the true solution? It is the combination of the two systems which offers this. How shall we then proceed to make an installation for electric lighting in an entire city? You may suppose, if you please, that there is available at the outskirts of the city, or even at quite a distance, a waterfall or other motive power, but this will not essentially alter the principle of what I propose. If we had to undertake the installation with the Edison system alone, we should be compelled to abandon any transmission from the outside. We would divide the city into districts of limited area and install at the center of each a central station for the production of the current. This layout would be exceedingly expensive as regards first cost of installation on account of the multiplicity of central stations, and would not even be possible in every case, because it is not always easy to find a large building within the quarters densely populated, and furthermore, the neighborhood of a central station is always the subject of complaints and controversies. On the contrary, the enterprise becomes possible and probably less expensive by establishing a single central station outside of the city, should motive power be available at this place. From this central station would extend a transmission line at very high pressure, according to the Gaulard and Gibbs system, which would carry at a small cost the current to the center of the different districts, where it would be transformed by means of secondary generators into a current of low potential, as required by the lamps for parallel distribution, the only system of distribution practicably possible. This current would then be distributed within the district by means of an Edison distribution, two-wire or even three-wire, according to the more economical system which is at present adopted extensively in America by the central electric-light stations. This would be the most ideal solution, because it would utilize the properties and advantages of the two systems, combining their respective good points without one system interfering with the other. This would then be the radical solution of the problem of house-to-house distribution of electric light and, when the case, of the utilization of natural forces for the lighting on a large

scale. But is this solution possible at present? I could not answer the question. In the Gaulard and Gibbs system, as actually exhibited at Turin, there is more progress to be made, modifications to be introduced and difficulties to conquer. It will be necessary to find out if and how we can build large dynamos for furnishing current of intensity sufficient for feeding a whole district, or part of a district, if there will not be obstacles to the use of such high potentials; because we shall necessarily be compelled for making such application to use very much higher voltages than the 2000 volts of the Turin generator. Along similar lines there is a whole series of difficulties to be solved from the point of view of installation and operation of a single central station for the production of the current; and finally, we must not forget the question of the losses due to the transmission and transformation of the primary current, for the influence that these losses would have either upon the cost of first installation, or upon the cost of operation, especially in the case where steam engines are used. But these are in my opinion questions of secondary importance, and one can hope that in time the genius of the men who have had the first conception of these systems of distribution will arrive at a solution of these questions in such a manner as to answer all the exigencies of practice."

Since this clear exposition of the theory of the correlation of transmission and distribution was made in 1884, great progress has been made in the applications of electricity, but it is remarkable that in no essential features have the systems as developed departed from the general lines conceived at that time.

There have been and there still are differences of opinion as to more or less important details, but the general idea set forth in the above lines, of a single generating station transmitting high-tension current to centers of distribution, which is then transformed to lower potentials for supplying the translating devices, has been the keynote of all the later developments. The problem of distribution is at present narrowed down to the consideration of engineering and commercial features, which must now guide the engineer.

One of the main points to solve is, how shall we distribute the low-potential current to the translating devices? We are thus brought to face the selection of a system which will give the most satisfactory result, and we are, accordingly, to select between overhead lines or underground distribution, direct-current system

or alternating current, and whether single-phase or polyphase systems, and of two, three, four or five-wire distribution, the selection of the suitable voltage for translating devices and a number of other similar questions.

Now by defining any of these features we affect the whole system and give a characteristic stamp to practically every piece of apparatus required for the generation, distribution and utilization of electric current. It is evident, therefore, that on account of the complexity of the problem the systems of distribution cannot be studied from the standpoint of theory alone. We can, with the aid of mathematics and physics, analyze special features of any one system, but when we want to make the applications we must always bring to bear all the commercial and practical considerations which are also factors of the problems and which cannot be expressed by formulas.

To study intelligently any one problem one must have before him the most salient conditions to be met. Among these characteristic conditions are the following:

(1) *The amount and character of business,* whether in a large city with an installation of incandescent and arc lamps and motors mostly operated at variable speed, or in a small city with incandescent and arc lamps and motors mostly operated at constant speed, or whether in a factory plant having a great number of variable-speed motors, or in a cotton mill having only motors requiring absolutely constant speed.

The relative percentages of the different classes of businesses and other matters of relative importance will very often point to the selection of a particular system of distribution.

(2) *The local field of development.*—A survey of the existing installations and of the character of competition to be met will also be of paramount importance in the development of a central-station business. If, for instance, a company expects to connect to its system a number of customers already supplied with current by local plants, it would be of importance to select a system that would fit the conditions of these installations.

(3) *The density of distribution* is a factor of great importance and, in fact, sometimes it alone determines the selection of the system independently of other considerations.

(4) *The local conditions of cost of real estate for sub-stations* required by certain systems or the value or servitude of rented

spaces in private buildings required by other systems will be a special feature to be considered for each locality.

(5) *The fire hazards* from electric service are subject to more or less stringent regulations, especially for the installation of high-tension transforming apparatus, and also the customer's wiring and applicances, which will necessarily influence the selection of the system to be adopted. Municipal regulations also prescribe in some cases that distributing lines should be put underground rather than overhead, and also regulate the maximum voltage to be adopted in streets and in buildings.

(6) *Patents and questions of policy* do not always permit a free hand in the purchase of station apparatus as well as supplies, and these considerations must be given due weight in the selection of a system.

(7) *The cost of capital* for these enterprises varies in different localities and largely influences the ultimate results.

(8) *The cost of station supplies,* as for instance, coal and water, as well as labor, are of paramount significance in shaping the lines to follow.

General considerations of the above character are usually sufficient to determine the main features of the system to be selected; or at least they will shape the problem within well-defined limits, which will point to only a few alternative solutions which can then be treated on their respective merits.

It would be impracticable to attempt to co-ordinate the knowledge we have of the different systems in order to arrive at general conclusions which could then be applied to any individual case. There are, however, general features that any system must possess, and among them the most important are the following:

(a) An ideal system should be of the greatest simplicity. It should not require any complication whatever at the customer's premises, and it should be safe and entirely devoid of danger to life. Simplicity in the distributing lines is essential for satisfactory operation and maintenance. Simplicity at distributing stations is also highly desirable, though not as essential as in the other two cases.

(b) A distributing system should be as uniform and flexible as it can be made. A growing system will require a certain flexibility for meeting new requirements without discarding the greater part of the original apparatus. Uniformity of size and standardization

in different parts of the equipment will assist this evolution. This applies to all parts of the system, from generator to translating devices.

(c) A system must be as economical as possible to install and to operate, at the same time fulfilling the requirements it has to meet.

(d) A system must be reliable. Local conditions will require the adoption of different standards. The importance of a high factor of safety will grow with the importance and size of the plant. In general, one must keep in mind that, for instance, in a large city the lighting of a hotel, theater, public building or even a private residence is very often of primary importance according to the use made of the service, but only of secondary importance as to the cost of maintenance; and continuity of service must not, therefore, be handicapped unless very material advantages are to be derived from a system less reliable in operation. In other cases the value of a high factor of safety is more largely subordinated to the cost at which this reliability is obtained.

We may now see how the different systems commonly used in practice comply with these general requirements.

For convenience we may subdivide the systems into *overhead* and *underground,* the distinction being more adapted to differentiate requirements of service than essential differences of method.

Outside of local installations for factories or other plants for special local purposes, we may broadly state that overhead systems are applicable where the territory covered is scattered or the demand for current is light. Underground systems instead are only applicable to territories densely built up with heavy demand for current.

In the case of overhead distribution for lighting in scattered districts, single-phase distribution is usually preferable; two or three-phase generators can be used at the station, and the additional power wires required for any motor installation above 10 or 15 horse-power can easily be strung on the existing pole lines without heavy extra cost. The problem does not present great difficulties, and the engineer is governed by common practice.

In the case of underground distribution in heavily loaded districts, one usually finds an existing system already fully developed, and the extension of that system is usually a foregone conclusion.

There is no definite line of demarcation between these two cases, and it would be difficult to say when it would pay to put an overhead line underground. There is, however, no doubt that when

a system has reached a density of about 1000-kw demand per square mile, the extra cost of an underground system is no longer prohibitive, and the standard of the service would be materially enhanced. There are now in America a number of such overhead systems, which have grown to large proportions and which will gradually be put underground in the near future.

It is in these cases particularly that the engineer will be called upon to select a system which will meet the new conditions, and it is precisely in these instances that one is liable to find great differences of opinion among engineers. As this is an important subject of live interest, I shall take a practical case upon which to fix the ideas in the general discussion of the problem of distribution.

Let us assume a concrete case of a medium-sized city, covering a territory of say 10 square miles, and having at present the following classes of service:

Series city lighting,	750-kw max., series direct current.
Multiple incandescent and arc lighting,	1500-kw max., alt. cur., single-phase.
Power service,	750-kw max., 500-volt direct current.
Total,	3000-kw max.

Of the total amount of station output, the business section of the city covering, say, one-half a square mile, would take about the following percentages:

City lighting,	10% —	75 kw
Incandescent,	75% —	1125 kw
Power,	80% —	600 kw
Total,		1800 kw.

The existing customer installations in this district would consist say of 150 series arcs, 40,000 equivalent 16-cp incandescent lamps, 100 multiple arcs, and 1800 horse-power of motors. It is proposed to put this section of business underground. We shall assume that the location of the generating station is fixed by existing conditions, and that the alternating-current generators are wound two-phase, 60 cycles. For a first case we shall assume that the station is 5000 ft. distant from the center of the underground section. Let us then consider the systems that could be applied to the underground territory with the view of selecting a system that shall be *simple, flexible, economical* and *reliable.*

For the sake of simplicity of generation and distribution, we should adopt, if possible, a system having a common source of supply for all services, and a common set of distributing mains similar to the distribution of water and gas. For the sake of flexibility, the network of mains should be a meshed system, making a solid network of cable mains all of one or two standard sizes, so that extensions can be made without replacing any of the cable previously laid. To be economical, the system should require low fixed charges for interest and depreciation, have a high efficiency at maximum load and a good all-day efficiency. To be reliable any part of the distribution should be free from interruption of current on account of troubles at the generating end or at the transmitting and transforming apparatus. In this country it is customary to insure against any conceivable kind of losses and to consider too lightly the obvious safeguards against the failure of the light and power supply that moves the wheels of trade of the business section of an important commercial center, would be an unpardonable mistake of serious commercial detriment to the supply company. On the other hand, an almost absolute guarantee of reliability of service would be invaluable to the successful exploitation of the product. The remarkable success achieved by almost all Edison companies, with their splendid records of continuous uninterrupted service, gives an inkling of the great importance of some of the purely practical considerations not taken account of by theory.

Besides these general qualifications the system should have all those points of superiority that would make the service best adapted to the utilization of the current by present and prospective customers.

It is not probable that all of these requirements could be fully met by any one specific system. We shall have, therefore, to undertake several tentative solutions and then discuss the different results each on its own merits.

The first solution that suggests itself is the continuance of the existing system readjusted for underground conditions. The 500-volt power service and the series city lighting could be readily adjusted for underground operation. The standard American type of subway construction with its great flexibility would not present any difficulties in carrying out this work. For the incandescent lighting we would have to build a system of ducts for drawing in a number of single-phase circuits, feeding one or several trans-

formers at the centers of small districts, each covered by an independent small network of three-wire low-tension mains (Fig. 1). The transformers would have to be installed either in manholes under the street surface or in kiosks in the street or in the cellars of private customers. Any one of these locations is more or less objectionable. The manhole location requires perfect sewerage conditions, and also requires for reliability of operation that each

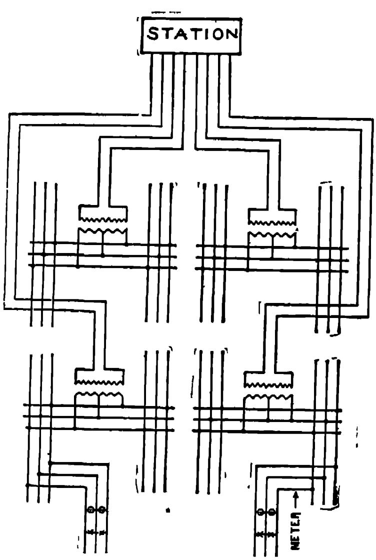


Fig. 1.

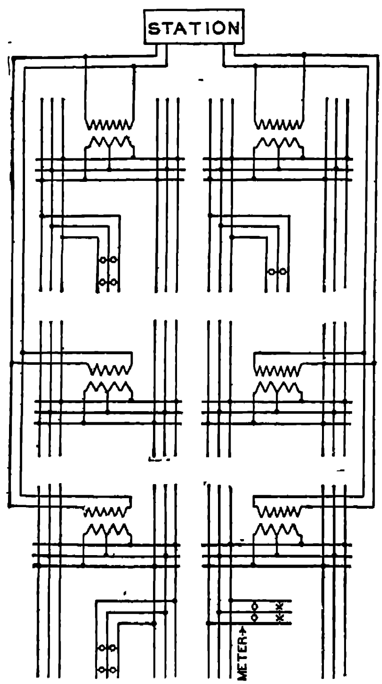


Fig. 2.

transformer be fed by a separate feeder, thereby eliminating the primary fuses which are unreliable in a manhole, and also in some cases making possible the use of transformers of low iron and high copper loss, and regulated by individual regulators for each feeder. Transformer-houses or kiosks on business streets are seldom practicable, but would be fairly satisfactory in operation. When insurance regulations allow it and convenient leases for long periods can be arranged, the private building location is preferable. Transformers in this case should be installed in suitable enclosures, these enclosures being accessible by a locked door preferably opening

on the street, or in any event always accessible at any hour of the day or night. The dependence upon a number of private owners is, however, somewhat of a drawback in most instances where this system is in use in this country.

Let us assume to have settled upon a definite location as found best suitable for the conditions. In the case of manhole transformers for commercial and technical reasons, it will be advantageous not to make the transformers and districts too small and for safety not too large. We can then decide upon say 12 100-kw transformers, supplying 12 independent districts. For emergency conditions we shall provide suitable switches for tying together neighboring districts, thereby making it feasible for the trouble man to give temporary relief to a district which through the failure of its primary feeder or transformer has been put out of service.

In the case of transformers in kiosks or private buildings, we may safely use secondary fuses with the transformers and connect several of them so as to feed into a large meshed network of mains. We may, for instance, divide the whole underground section into two districts designed to subdivide the load approximately equally between the two phases of the generators, and in each district have six primary feeders, with 100-kw transformers, as before, the only difference being that the secondaries of each six transformers would be connected in a meshed network of mains, each transformer being protected by secondary fuses or by circuit breakers in case of large transformers.

By using different criteria in design and adopting good regulating transformers, we may arrange the primary feeders for the two districts last mentioned in a different manner. We may use two single large feeders connecting all six transformers in multiple for each district (Fig. 2). This arrangement requires primary fuses for each transformer and independent secondaries for each transformer district. To mesh into a network also the secondary mains of the six districts, thereby forming a meshed primary and meshed secondary, distribution would be unsafe owing to the difficulty of properly subdividing the loads among the different transformers; this is, however, done in some cases and with proper protective devices and careful study of the layout the system might be made operative. It is understood that with this system the regulation of all six transformers being done at the station upon a

single feeder, this must be designed for a small maximum drop not to exceed, say, 2 per cent, otherwise poor regulation will result. The all-day efficiency of the system is, however, lower than in the case of the individual feeders for each transformer; it is, therefore, better adapted to plants where energy is cheap, as in water-power plants.

The solution of our problem along the above lines would not give us the desired unification of the generating station; the subdivision of the underground system into small districts would not give us the advantages of a meshed network, thereby reducing to some extent its flexibility and largely the reliability of service of any one district. In fact this continuity is dependent exclusively upon the year in and year out absolute freedom from failures and breakdowns of any part of the long cable feeder and transformer supplying the network of mains in the district.

As to economy, one can see without making calculations that the three independent systems of generation and distribution of current for the three separate classes of service cannot lead to maximum economy of investment and cost of operation and maintenance.

The unification of generating apparatus can readily be decided upon from the considerations of respective percentages of power required for different services. As 50 per cent of the total output is for alternating 60-cycle lighting, 25 per cent for direct-current series arc lighting and 25 per cent for 500-volt power, and as the alternating current 60-cycle service for the overhead distribution is a necessity, the selection of alternating-current 60-cycle generation is a foregone conclusion. The series direct-current service could, in the majority of cases, be economically transformed into a series alternating-current system with constant current transformers; or if preferable, the direct-current arc machines could be operated by alternating-current motors, the selection depending upon consideration of local requirements. Whatever developments in the art of arc lighting may follow the investigations and experiments that are now being made, they will not be in the way of the direct or indirect use of alternating current. The 500-volt power generation could be obtained from motor-generator sets, the motors being operated from the 60-cycle alternating-current supply. It is, however, doubtful if the existing 500-volt generating units are reasonably efficient, that it would pay to dis-

card them and add the investment of new motor-generator sets. In many cases, we may, therefore, have to abandon the idea of unification of generating apparatus and possibly only add some synchronous motor-generator sets that would tie together the two systems and serve as reserve, and also for shutting down the system at light loads.

We would, therefore, have a composite station with 75 per cent in alternating-current generating capacity and 25 per cent 500-volt direct-current generating capacity. Any further step toward unification of the system will depend entirely upon what can be accomplished in the unification of the distributing system in the underground district representing the bulk of the commercial light-and-power service. We may neglect the question of the city series arc in this district, as most probably the series alternating-current system would do for the case or multiple arcs fed from the lighting mains could easily be adopted, if found convenient. The serious question to face is the supply of current to motors. If single-phase alternating-current motors could be made to operate under the same conditions that direct-current motors are operated, there is no question that even at the large sacrifice of replacing with new alternating-current motors, the 1800 horse-power of customers' motors, it would pay in the end to do it, as we would save the duplication of separate mains for light and for power and we would be in the position of securing the advantages of unification of station apparatus and more economical operation. At present single-phase alternating-current motors cannot meet these requirements and, as the several attempts to develop a commercially satisfactory single-phase motor have been only partially successful, we may exclude it from consideration. The promises held forth in the field of single-phase railway motors may eventually bring the long-wanted solution, but at present, while there are undoubtedly many cases where single-phase motors could and should be used, we still shall have to operate the 500-volt power circuit for a number of cases where the present single-phase motors are not applicable. Therefore, we are brought to the conclusion in favor of a composite alternating current and 500-volt direct-current generating station and duplicate system of distributing feeders and mains for light and for power. This conclusion seems hardly logical, but there are open only two other alternatives, which are hereafter discussed.

The first alternative is the adoption of polyphase-current distri-

bution for the underground district as used for the overhead district. The second is the distribution of direct current through an underground Edison three-wire system. Before comparing these two systems, we must make a statement of fact that as far as the electric service requirements in the business section of a city are concerned, the direct-current systems have no drawbacks to contend with in the unlimited variety of their applications, while the alternating-current systems, without any advantages in efficiency, are, in many cases, handicapped by limitations in their adaptabilities to meet important uses, as for instance in the case of variable speed motors for elevators and hoists and the direct charging of storage batteries. The greater adaptability of direct-current motors in city work is, in the case of low-speed motors, usually accompanied by lower first cost and higher efficiency of operation. Another consideration is the presence in a business section of quite a number of private plants, all operating direct-current generators and translating devices. Central station break-down connections for these prospective customers become impossible with alternating-current systems of distribution, and their limitations in adaptability to specific services and the difficulties encountered in readapting the existing installations of motors and arc lamps make the eventual full central station service to these customers very difficult to secure, without making local installations of direct-current converting apparatus to be operated continuously. A few large installations of this kind would weigh a good deal in the final results. Returning now to the study of the application of polyphase and direct-current systems, we shall take up first the polyphase system.

Having at the generating station two-phase generators, we shall lay out an underground two-phase system. By rewinding the generators it may be feasible to use three-phase distribution if we shall find it preferable. The two-phase distribution could be accomplished according to several plans. One plan would be to adopt the single-phase distribution for light by districts, as in the previous case, and parallel the system with primary feeders, transformers and a two-wire network of 220-volt mains of opposite phase for power (Fig. 3). The primary feeders could be two duplex cables or one three-conductor cable, using the third wire for the power circuit, regulators being mounted only on the lighting circuit. This system would not be less complicated than the previous system with 500-volt direct-current mains, its only advantage being the unification of generating apparatus at the station.

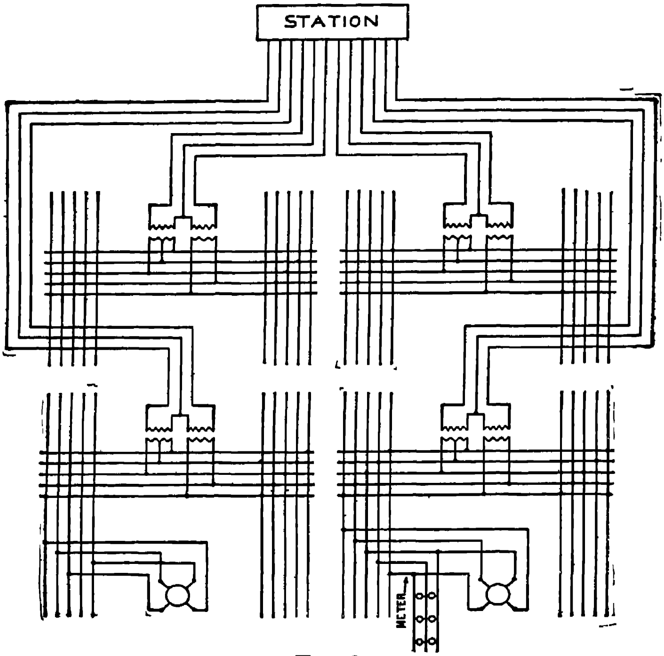


Fig. 3.

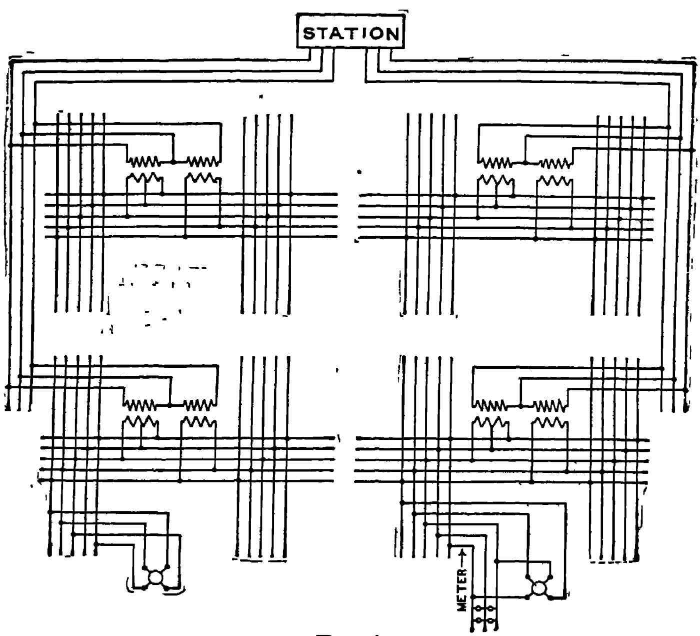


Fig. 4.

A two-phase three-wire meshed primary and a three-wire meshed network of 110-volt mains could supply light and power to the whole district (Fig. 4). It is an unbalanced system even at equal distribution of loads among phases; it requires a large amount of copper for mains, on account of the low voltage; the metering of current at customers' premises requires polyphase meters or two single-phase meters for each class of service; the neutral of the three-wire wiring in buildings must be of larger cross-section than the outside wires, which is not always the case in existing installations. On account of all these drawbacks, this system may be dis-

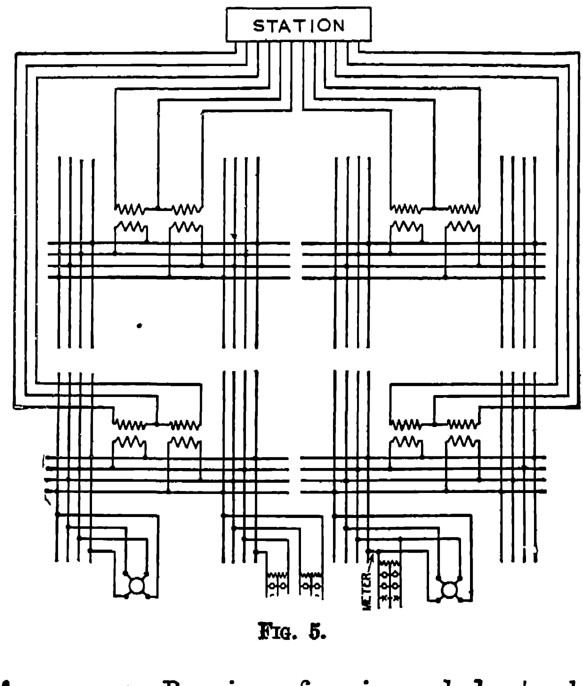


FIG. 5.

carded for our case. By using a five-wire meshed network of 220-volt mains, the total amount of copper for mains could be reduced, but it would add complications of wiring without corresponding advantages.

A duplicate three-wire single-phase system along the lines first described would have the advantage of good regulation with reasonable requirement of copper, but the six cable wires would be cumbersome and costly. By omitting the neutral wire and deliver-

ing 220-volt current for each phase the last system could be reduced to four wires, which would be an advantage if 220-volt incandescent lamps were as efficient and 220-volt arc lamps as satisfactory as 110-volt lamps. In the *Transactions* of the American Institute of Electrical Engineers, 1901, Vol. XVIII, pp. 861–869, the writer demonstrated that for conditions similar to the ones under consideration, it would not be economical to use 220-volt lamps. The tendency upward due to the advantages of high voltages in the case of the Nernst lamps is now offset by the tendency to lower voltages in the osmium lamps. We have, therefore, to discard the system as unsuitable for our conditions. We could, however, install at each customer's premises a balancing 2 x 110-volt transformer, which would permit us to use the two-wire 220-volt mains and the more efficient 110-volt lamps (Fig. 5). In most of the cases this arrangement would work well, but in a dense district such as we have under consideration, the first cost of these balancing transformers, together with their losses would undoubtedly make the system as expensive as the neutral main wires which they replace. This system is, however, the best that can be made out from a two-phase distribution, and we shall, therefore, give to it further consideration in our final selection.

If we adopt three-phase generators we can select between a three-wire or a four-wire system for the primary feeders and several combinations of secondary mains. The straight three-wire primary would perhaps always be preferable; we would then use three-phase or two-phase T-connected transformers and make the combinations desired on the secondaries. We can then distribute through a three-wire network of 110-volt mains, but its cost would be high. We can distribute through a six-wire network of 2 x 110-volt mains but the six-cable mains would be cumbersome and expensive. We can distribute through a three-wire network of 220-volt mains, but it would not be economical on account of the low efficiency of 220-volt lamps. By the use of the balancing transformers (Fig. 6), we would obtain the best workable three-phase three-wire system, which we shall consider later.

By dividing the underground territory into three equal districts, and operating three-phase generators, one can lay out some system by which light is delivered single-phase by a three-wire network of mains for each district, and power from an additional two-wire cable main. This system, which works very well for overhead condi-

tions, would be expensive and undesirable for underground conditions.

From this review of the alternating-current systems with distributed transformers, we have found that the following systems are more or less desirable, but all of them possible for our conditions.

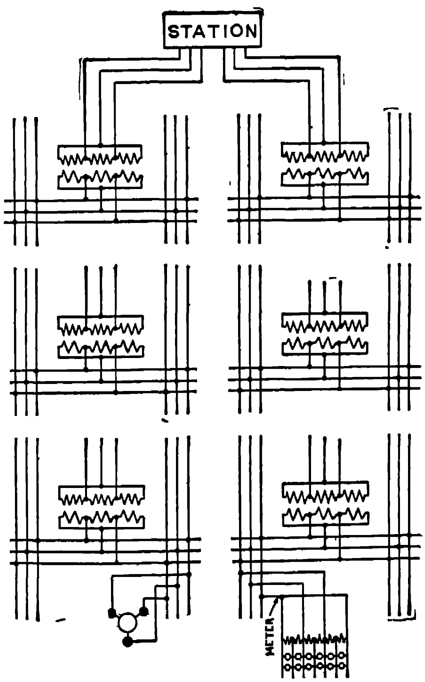


FIG. 6.

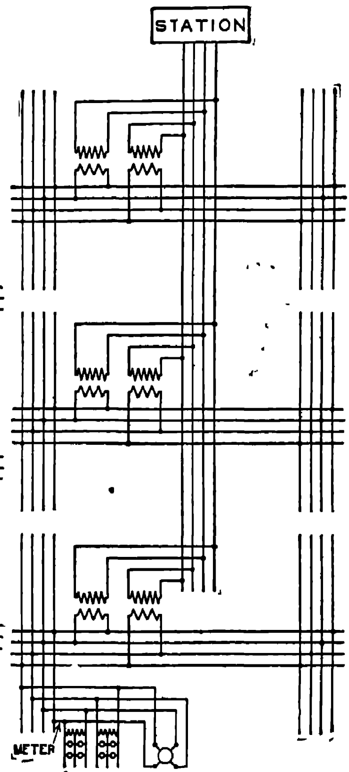


FIG. 7.

Case A. Single-phase distribution for light, 500 volts for power separate (Fig. 1).

(1) Twelve independent two-wire primary feeders, equally divided between the two phases, each one feeding a separate secondary district, consisting of a single-phase transformer supplying a three-wire, 2 x 110-network of mains.

(2) Same as (1), but with each group of the same phase of secondary-district mains connected in two solid meshed secondary networks.

(3) Same as (1) but with only two single-phase, two-wire primary circuits, one for each phase, meshed primaries (Fig. 2).

Case B. Two-phase distribution for light and power.

(4) Twelve independent three-wire primary feeders, each one feeding a separate secondary district consisting of a set of two-phase transformers, supplying a three-wire 2 x 110-volt network of mains, and a two-wire 220-volt network, the latter being used for motors only (Fig. 3).

(5) Same as (4), but with two halves of the district mains connected in two solid secondary meshed networks.

(6) Same as (4), but with only two sets of two-phase primary circuits, meshed primaries (Fig. 4).

(7) Twelve, or less, two-phase primary circuits and sets of two-phase transformers with twelve, or less, districts, covered by duplicate two-wire 220-volt single-phase network of mains, with balancing transformers at customers' premises for lighting, the lighting of each customer being from one of the single-phase circuits, the balancing of phases being accomplished by distributing evenly the customers' connections between the two phases (Fig. 5).

(8) Same as (7), but with the mains of all districts connected in a solid meshed secondary network.

(9) Same as (7), but with only one set of two-phase primary circuits, meshed primaries (Fig. 7).

Case C. Three-phase distribution for light and power.

(10) Twelve, or less, three-wire three-phase primary feeders, each one feeding a separate secondary district consisting of a three-phase transformer supplying a three-wire 220-volt three-phase network of mains with balancing transformers at customers' premises for lighting, the installations of any importance being wired for three independent three-wire circuits, one for each phase (Fig. 6).

(11) Same as (10), but with the mains of all districts connected in a solid meshed secondary network.

(12) Same as (10), but with only one set of three-phase circuits, meshed primaries (Fig. 8).

As an alternative to any of the above systems with distributed transformers, we may select equivalent secondary networks of mains, fed by low-tension feeders from a single sub-station, at which are located all the step-down transformers. As we have already noted the practical drawbacks of distributed transformers in a heavily-loaded district, it is important to give the case of a sub-station thorough consideration. The objections to the distribution of large amounts of alternating current, through lead-covered cables, are in

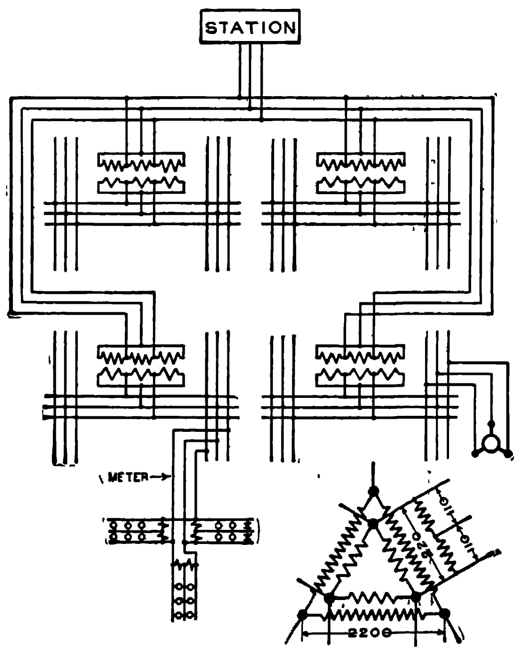


FIG. 8.

practice less serious than one would expect. Care must be taken in the sub-station and subways to eliminate looping of phases with iron pipes or other magnetic materials, but the difficulties would not be greater than in all other wiring for alternating-current distribution.

For our underground district, we could apply four layouts corresponding to (2), (5), (8) and (11), which we shall designate respectively by the numbers 13, 14, 15 and 16.

(13) With a single-phase for lighting and 500-volt direct current for power, the alternating-current distribution from sub-station could be accomplished by dividing the system into two equal and independent sections, for balancing the phases of the two-phase generators, and feed the two sections, each covered by a meshed network of mains, by means of low-tension feeders in the same manner that Edison three-wire systems are

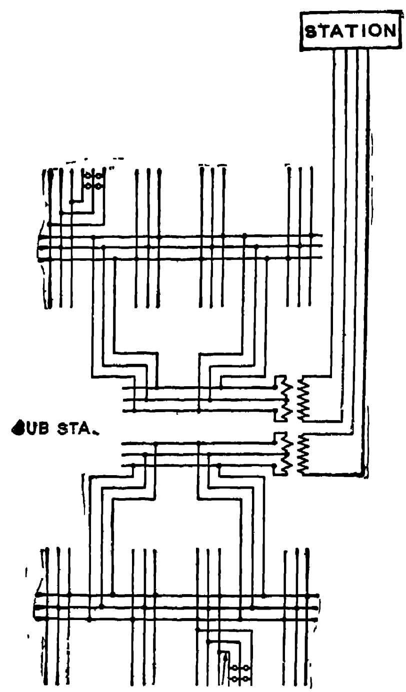


FIG. 9.

operated. For feeders and mains the Edison tubes would fill the requirements exceedingly well, though for practical reasons cables would be preferable. In case of cables the feeders should be of multi-conductor type, making them the equivalent of an Edison three-wire tube; the mains should preferably be single-conductor cables. The regulation of each feeder

could probably be efficiently obtained by having the secondaries of the step-down transformers built with a neutral tap at the middle and a 10 per cent or 15 per cent tap on each end, each tap being connected to corresponding station busses, the middle bus being for the neutral of the feeders and the two sets of outside busses being intended for connecting of an auto-transformer regulator mounted on each outside leg of the low tension feeder. The two regulators would give perfect regulation for drop in feeders as well as for unbalancing of the two sides of the three-wire system. The single-phase two-wire 220-volt distribution with balancing transformers at customers' premises would save the neutral wire of feeders and mains; a balancing transformer at the end of each feeder would save the neutral feeder wire. In the

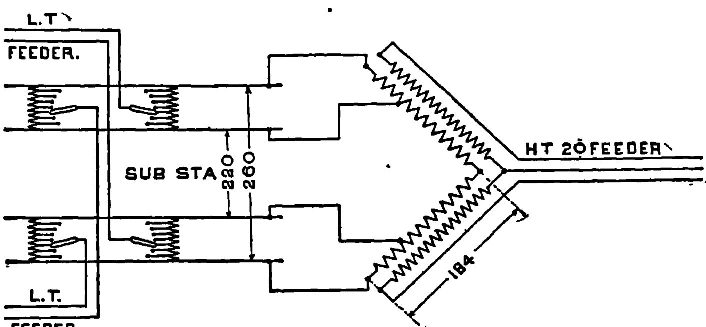


FIG. 10.

case of a two-wire 220-volt distribution with balancing transformers, it may be desirable to distribute the two-phase current, single-phase, from a single set of busses into a single meshed network of mains. This could be done by using the transformers of special design and of somewhat larger capacity, connected in two-phase relation on the primaries and the two secondaries in series delivering single-phase current (Fig. 10). The secondary winding must be specially designed for avoiding magnetic unbalancing on account of the regulating taps on one end of each transformer.

(14) With two parallel sets of low-tension feeders and mains, one single-phase three-wire for lighting and power, and one alternating-current two-wire 220-volt for power only, the system would require similar layouts, as just described for the single-phase system (13), with the addition of two-wire circuit feeders and mains for which, however, no regulation would be required at the sub-station, thereby making the sub-station connections rather simple and perhaps also

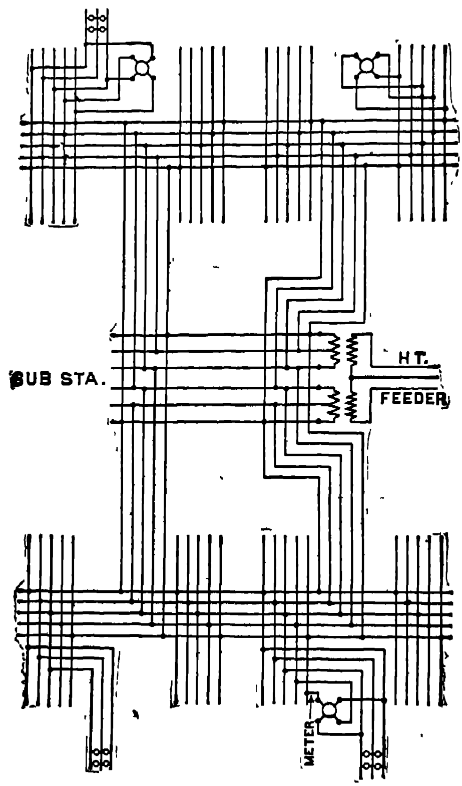


FIG. 11.

poor regulation in the line permissible. With this system it would be necessary to operate the underground districts divided into two equal sections operated from two busses (Fig. 11). With balancing transformers at the end of lighting feeders or at cus-

tomers' premises, the neutral wire in feeders, or feeders and mains, could be saved, thereby making the distributing system four-wire instead of five-wire.

(15) By connecting lights on both circuits of the four-wire system last mentioned, we would have independent wires, two-phase distribution with two wires, 220 volts on each phase and balancing transformers at the customers' services. The balancing of phases would be accomplished from house to house. The secondaries would form a solid meshed network of four-

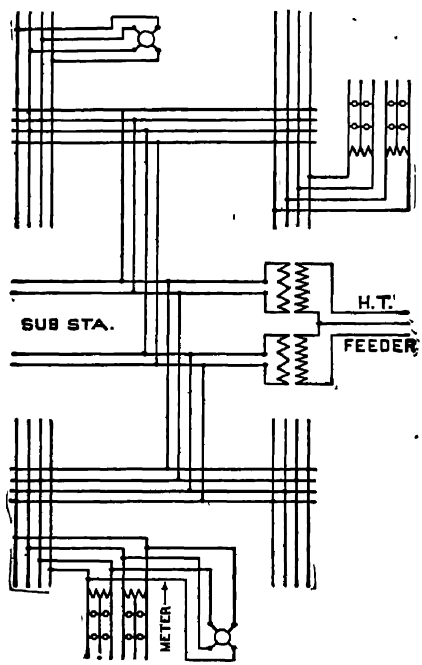


FIG. 12.

wire mains. Both mains in each street require regulation at the sub-station and same regulation in lines (Fig. 12).

(16) Three-phase low-tension distribution can be done by three-wire 220-volt feeders and mains and balancing transformers at customers' premises, balancing of phases being accomplished by subdividing important

lighting customers' wiring in three equal and independent parts, one for each phase (Fig. 13). Independent regulation of each phase is practically impossible with this system; each phase being dependent upon a fixed relation to the other two, making it necessary to act at the same time and in different degrees upon all the phases. This regulation can be accomplished better on the high-tension side of the three-phase transformer by individual regulators on each of the three legs. In practice with generators of good regulation and a large network of three-phase low-tension feeders and mains mesh connected in conjunction with the compensating effect of all three-

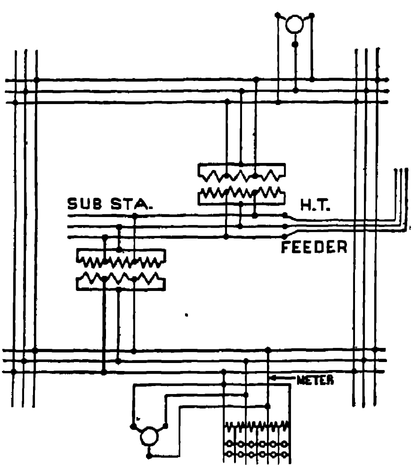


FIG. 13.

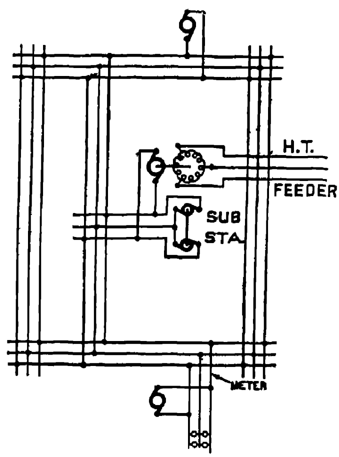


FIG. 14.

phase motors, it is probable that independent regulation of phases could be done away with. It would be necessary for the regulation of each feeder to provide a step-down transformer with its primary regulator for each feeder which, however, is not a drawback, as in our case transformers of 200 or 300-kw capacity could be used. This would give the greatest independence, but it requires the continuous operation

of all step-down transformers, unless some combination of switches is arranged on the feeders at the sub-station, by means of which a combination of two or three feeders can be operated from a single transformer and the underload transformer cut out of service. Accordingly, for the last conditions, which are preferable for good service, the transformers should be designed for highest full load efficiency, while in the case of continuous operation they should be designed for lowest iron losses.

While it is theoretically possible to make a sub-station layout which would not require station attendance, this would not be suitable in practice.

We have thus described the possible layouts for alternating-current distribution. By the use of a sub-station with motor-generator sets, we should feel justified in excluding rotary convertors on account of the 60-cycle frequency, we may distribute direct current to an Edison three-wire system covering the underground district with a solid meshed network of mains (Fig. 14).

(17) By the use of 250-volt lamps and three-wire 2 x 250-volt mains, existing motors could be operated from the same lighting mains, but we have already pointed out the undesirability of this plan for our conditions — first on account of the low efficiency and higher cost of renewal of high voltage lamps and inferiority of arc lamps and also on account of making necessary the rewiring of all old customers' buildings.

(18) With two 110-volt mains, the existing 500-volt motors would have to be rewound but no important changes in customers' wiring would be required. If direct-current distribution were selected, this system, while more expensive, would perhaps be preferable to the 500-volt three-wire system, on account of the superiority of 110-volt incandescent and arc lamps.

For the 18 possible solutions of our problem above outlined we have pointed out a few of the advantages and disadvantages of each system; now by applying some of the general practical con-

siderations we should be able to select among the 18 cases a few that would best suit our conditions. But before proceeding to this elimination we may first figure out the relative economical values for all cases so that our selection may be guided by this requirement as well as by all other requisites of the conditions we have assumed.

In Table I we have given on general lines the main items of cost which are variable for different systems, leaving out of consideration small details and items which would be practically identical for all systems.

The title with the foot notes and comments of Table I explain the assumptions and points to be taken into account in making the comparisons.

The high-tension feeders have been figured for slightly different drops to fit the practical conditions, the lowest being 2.4 per cent and the highest 3 per cent for the length of 5000 ft. assumed in the case. (For larger distances of generating station from distributing centers the line drop and cost of high-tension feeders would be correspondingly increased.) The average maximum line drop of low-tension feeders has been assumed as 11.6 per cent for the 500-volt power circuits and from 5.2 per cent to 9.4 per cent for low-tension feeders for lighting or for light and power combined. The line drop in mains was in all cases very close to 1 per cent.

The efficiency of transformers at full load has been assumed at 97.5 per cent in all cases, and the efficiency of motor-generator sets at 85 per cent. Column G giving the maximum load efficiencies has been worked out from the above figures. The average load efficiencies of column H were estimated for the most favorable conditions.

Table I shows cost of cables and transforming apparatus for 18 possible solutions of the problem of putting underground the present overhead distribution in the business section of a medium size city now supplying 1200-kw maximum alternating-current lighting 600-kw maximum, 500-volt direct-current power, to an installation of 42,500 equivalent 16-cp incandescent and arc lamps, and 1800 horse-power of direct-current motors. The section covers one-half square mile with 69,000 ft. of streets with mains, and its center is assumed to be 5000 ft. from the generating station, equipped with 2200-volt two-phase 60-cycle alternating, and 500-volt direct-current generators.

TABLE I.

System.	High-tension feeders *A*	Low-tension feeders *B*	Low-tension mains. *C*	Balancing transformers *D*	Transformers or motor generators *E*	Total. *F*	Total efficiency of system. At maximum load. *G*	Total efficiency of system. Average all day. *H*
1 and 2...	$34,080	$25,220	$81,110	....	$8,400	$148,810	91%	91%
3...	17,280	25,220	81,110	....	8,400	132,010	91%	88%
4 and 5...	35,500	5,220	95,910	....	13,000	149,630	93%	92%
6...	23,184	5,220	95,910	....	13,000	142,314	93%	91%
7 and 8...	35,500	6,960	71,760	$7,000	13,000	134,220	93%	92%
9...	24,835	6,960	71,760	7,000	13,000	123,555	94%	90%
10 and 11...	35,500	5,220	66,240	10,000	15,000	131,960	94%	93%
12...	24,835	5,220	66,240	10,000	15,000	121,295	94%	90%
13...	12,500	56,266	81,110	....	6,000	155,876	85%	89%
14...	18,750	45,632	95,910	....	9,000	169,292	85%	89%
15...	18,750	46,750	71,760	7,000	9,000	153,260	85%	88%
16...	18,750	28,180	66,240	10,000	9,000	148,730	86%	89%
17...	18,750	18,181	44,505	....	50,000	131,436	80%	82%
18...	18,750	38,900	66,240	....	50,000	173,922	74%	77%

No. 1, No. 2, No. 3. Mixed systems, single-phase, alternating-current lighting, and small motors with high-tension feeders to 12 transformers feeding low-tension three-wire mains, with 500-volt direct-current power mains.

No. 4, No. 5, No. 6. Single-phase lighting, as before, but alternating-current, two-phase power in place of the 500-volt direct-current distribution.

No. 7, No. 8, No. 9. High-tension feeders and two-phase lighting and power from four-wire low-tension mains.

No. 10, No. 11, No. 12. High-tension feeders and three-phase lighting and power from three-wire low-tension mains.

No. 13, No. 14, No. 15 and No. 16. Respectively similar to No. 2, No. 5, No. 8 and No. 11, but with transformers in sub-station and low-tension feeders to mains.

No. 17. 500-volt, three-wire distribution for light and power from sub-station with motor-generator sets.

No. 18. 220-volt, three-wire distribution from substation with motor-generator sets.

Before comparing the values in column *F*, we must make a number of corrections and allowances which could not be readily incorporated in the table. Among the most important are the following:

(a) No figures were given for cost of ducts, the difference between the several systems being probably small except in cases where double distributing ducts are required. In the eight cases No. 1 to No. 6 and No. 13 and No. 14, all having five-wire distributing mains, it will be necessary to have double distributers which, figured on an increment cost basis, would amount to say $23,000.

(b) For cases No. 4 to No. 12 and No. 14, No. 15 and No. 16, distributing polyphase current for power, we must add the cost of replacing the existing 1800 horsepower of direct-current motors with alternating-current motors. For our estimate we may assume this cost at $50,000.

(c) For case No. 17 we would have to rewire practically all the existing customers' incandescent and arc lamp installations at an estimated cost of say $50,000.

(d) For case No. 18 we would have to rewind or replace all 500-volt motors with 220-volt motors at a cost of say $25,000.

In Table II, column F_1, are given the revised values with the corrections (a), (b), (c), (d), added to column F of Table I. For comparing the cost of different systems we must use column F^1 of Table II in the case of existing installations; for the case of new business we must use either column F or column F^1, according to whether the new business is for a customer not already supplied with current or otherwise. The importance of existing private plants operating in the territory, the annual rate of increase and the ultimate growth of business will decide which course to take in the comparison. The conditions for the future are, however, in most cases difficult to judge, as they are dependent upon new and unforseen developments. Therefore, unless a proposition can show more or less immediate advantages on its own merits under existing conditions, we shall assume that it would be entirely speculative and unsafe to follow. In our present case of a medium-sized city, whose business grows at a rather moderate rate from year to year, we feel justified in assuming that the system selected must show substantial immediate advantages under present existing conditions rather than distant future savings. Therefore, while we will give due consideration to the final results we shall, however, be guided more in our selection by the values given in column F_1 of Table II than by the increment values of column F of Table I.

To reduce the relative values of efficiencies to a money basis we have assumed a load factor of 25 per cent and figured out the total losses in Table II on the basis of an increment cost of production

of one cent per kw-hour. (With cost of coal very high or very low or with water power plants this figure may be either too low or too high.) In the case of systems requiring a sub-station we have added $3000 for its cost of operation.

TABLE II.

System.	Total cost of system.	Yearly cost of inefficiency losses.	Yearly cost of sub-station operation.	Total yearly cost (M + N).
	F+	*M*	*N*	*P*
1 and 2	$171,810	$2,500	....	$2,500
3	155,010	3,400	....	3,400
4 and 5	222,650	2,200	....	2,200
6	215,314	2,500	....	2,500
7 and 8	184,220	2,200	....	2,200
9	173,555	2,750	....	2,750
10 and 11	181,960	1,900	....	1,900
12	171,295	2,750	....	2,750
13	178,876	3,100	$3,000	6,100
14	242,292	3,100	3,000	6,100
15	203,260	3,400	3,000	6,400
16	198,730	3,100	3,000	6,100
17	181,436	5,500	3,000	8,500
18	198,922	7,500	3,000	10,500

With the aid of Table II and all that has been previously said, we may now proceed to analyze the several solutions with the view of making the final selection.

Systems No. 4, No. 5, No. 6 and No. 14, the most expensive as to first cost, have no special points of superiority to commend them to us, and we shall, therefore, exclude them from further consideration.

System No. 17, while reasonably economical as to first cost, is inefficient, its losses being only exceeded in one other case; and furthermore, it requires the operation of inefficient and more expensive high voltage incandescent lamps and unsatisfactory arc lamps. This system is, therefore, unsuitable for our conditions.

Systems No. 3, No. 9 and No. 12 require low investment and are all reasonably economical. The essential feature of all three is the presence of only *one* or *two* high-tension feeders supplying all the current for the underground section, this section being divided in numerous independent districts of distributing mains. There is no question that the resultant economy is accomplished at a heavy sacrifice of the reliability of service, and it is questionable if a similar plan would be given preference when almost as good re-

sults could be obtained with the corresponding systems No. 2, No. 8 and No. 11 having several independent high-tension feeders supplying current to one or two solid meshed networks of mains. We shall, therefore, have to select from systems No. 2, No. 8 and No. 11. (The systems No. 1, No. 7 and No. 10 are practically identical with No. 2, No. 8 and No. 11, but the latter are preferable if they can be adopted having a solid meshed network of mains instead of subdivided districts.) Between No. 8 and No. 11 there is perhaps little choice. The costs are practically the same; No. 8 transmits two-phase high-tension current, three-wire, which is undesirable, but the line drop being less than 3 per cent this drawback is not serious. It has the advantage over the three-phase system No. 11, that each phase can be regulated a good deal more independently than the three-phase. In our case, having assumed to have two-phase generators at the station, we may give the preference to No. 8 over No. 11. Between No. 8 and No. 2 the differences are of greater moment. With slight differences in first cost and economy system No. 2 has the advantage of supplying direct-current power to motors, which requisite we assumed to be a desideratum in our case.

Between systems No. 15 (two-phase) and No. 16 (three-phase), the differences in favor of No. 16 are too trifling to counterbalance the greater advantage of absolute independent regulation of phases of No. 15. We shall, therefore, discard No. 16.

By successive eliminations we have brought the problem to the selection between four systems, No. 2, No. 13, No. 15 and No. 18. The last three require a sub-station while system No. 2 does not. If local conditions warrant the direct distribution from the generating station to transformers in manholes or customers' premises, system No. 2 has such marked advantages over the other three systems that its selection would be a matter of course. In case the sub-station is found necessary we must select between No. 13, No. 15 and No. 18. System No. 13 does not give us the desired unification of generating apparatus, but its advantages in first cost and efficiency together with the possession of the requisite of supplying direct current to motors will, without doubt, outweigh the drawbacks of a composite station, especially if we should equip the station, or if preferable the sub-station, with a motor-generator set as a tie and a reserve between the two systems. We have arrived at the above conclusions on the assumption that the gener-

ating station was within 5000 ft. of the center of the underground district. It is now important to note what difference it would make if the station were not so favorably located. Referring to Table I, we see that only columns *A* and *G* and *H* would be affected. If we assume to use high-tension cables of the same cross-section as before, the cost will increase in direct proportion to the length and the line drop will also increase in the same ratio. The values of *G* and *H* will change relatively in approximately equal proportion, and for the present investigation we shall not need to revise the deductions as far as deduced from the efficiency values of columns *G* and *H*.

The only limitations will be the difficulties of transmitting 500-volt current too great distances and the poor regulation of the alternating-current system with too large line drop. In general, it is improbable that the direct-current generators supplying the 500-volt power service be installed at a station very distant from the center of distribution; it is, therefore, reasonable to suppose that where the alternating current main station is at greater distances than two or two and one-half miles, there is also a direct-current, 500-volt subsidiary station near the distributing center. This is by no means an hypothetical case, as we find similar conditions in many places. Let us then assume that the previous conditions were changed to the existence of two generating stations, one direct current at 5000 ft. and one alternating current at 15,000 ft. from the center of distribution, all other conditions remaining the same. The larger station can be assumed to be better situated for operation. We should like, if possible, to discontinue the operation of the smaller station; the subject will, therefore, require careful study. Let us assume that it has been proved advantageous to do away with the direct-current station by substituting 500-volt direct-current motor-generator sets at a convenient sub-station, or change the 500-volt service if a better solution is available. The polyphase alternating-current system considered before would enable us to do away with the sub-station entirely but can we still transmit economically the alternating-current to a distance of 15,000 ft., as was the case where the distance was only 5000 ft.? By referring to Table I, column *A*, we find that if we multiply by 3 the values therein given, we obtain the approximate variation in the cost of feeders. This cost for system No. 8 or No. 11, which we have found to be the most desirable for polyphase

distribution, would amount to $106,500 for both cases. The cost for high-tension feeders in the corresponding cases, with sub-stations (system No. 15 and No. 16), would be $56,250, a difference of $50,250 in favor of the sub-station; this without considering the undesirability of very long high-tension feeders for separate district transformers.

We see then that after a certain distance, exceeding two or two and one-half miles, the problem of distribution becomes a problem of transmission. In such cases it is necessary to have a step-down sub-station at the distributing center.

For our new problem we shall then have to consider only the systems No. 13 to No. 18, suitably revised.

We may neglect the high-tension feeders to the sub-station, as they will be the same in all cases; from the sub-station we could distribute high-tension current to transformers distributed all over the system as in cases No. 1 to No. 12, but having to operate a sub-station it would be preferable to attain the advantages of direct distribution by locating the same at a convenient place, near the center of distribution of the underground district.

With the exception of system No. 13, the other five systems, No. 14, No. 15, No. 16, No. 17 and No. 18, would have the same relative values as in Table II. System No. 13, however, would have to be revised in so far that the 500-volt power cables would be somewhat cheaper on account of the sub-station being nearer the center of distribution than in the previous case. This saving is estimated at $12,000. On the other hand the cost of motor-generator sets would more than offset this saving; furthermore, it would be necessary to provide some reserve capacity. Making such allowances the net cost of system No. 13 would be increased at least $10,000. Other things being equal, the efficiency at maximum load and the all day efficiency will both be reduced about 3 per cent in each case. Therefore, the relative values of Table II for systems No. 13 to No. 18 will apply to the revised conditions with the exception of system No. 13, for which the total cost (F_1) will be $188,876. The yearly cost of inefficiency losses, column *M*, will amount to $4000, and the total, column *P*, will be $7000, instead of the values given in Table II.

Discarding systems No. 14 and No. 17 for the same reasons given before, we have now left to select between them four systems,

No. 13, No. 15, No. 16 and No. 18. Their respective values, columns F_1 and P, as revised, are as follows:

System.	F_1	P
No. 13	\$188,876	\$7,000
No. 15	203,260	6,400
No. 16	198,730	6,100
No. 18	198,922	10,500

The maximum difference in investment costs between these systems is less than \$15,000, while the difference in yearly costs of operation is \$3400. Estimating the total business affected to represent 2,500,000 kw-hours sold to customers, the maximum difference per kw-hour sold would be .14 cent. This would be the amount saved by the polyphase system, No. 16, over the straight direct-current system, No. 18. On the other hand, if we compare No. 13 and No. 16, the difference in cost of operation is reduced to \$900, or to less than 4/100 of a cent per kw-hour sold. In view of the preference for the direct-current motor assumed as a premise of our problem, the selection of system No. 13 becomes very evident. A great number of engineers would perhaps go as far as to select the straight direct-current system No. 18, but considering that with system No. 13 one may gradually develop considerable single-phase motor load in small units and save a good deal of the 500-volt cable investment in streets without motors; and as the present prospects of developments of variable speed alternating current motors are more promising in the single-phase than in the polyphase type, and as the single-phase distribution is superior for operation, for regulation and for cost and maintenance of meters at customers' premises, we would give it preference over the other systems. These figures and these conclusions may be somewhat surprising for two reasons: First, because it is not generally appreciated how an apparently inefficient system like the direct-current system can so closely compete with polyphase alternating-current systems on the very point of total cost of distribution and apart from other considerations of commercial or practical character as to the superiority of either system; second, because these close results appear to apply even to the case of relatively small centers where the density of current supply per foot of street is greatly below the average density found in large cities.

In the case of large cities it is, however, only pertinent to note that high-voltage transmission and the use of 25-cycle rotary

converters improve considerably the efficiency over the efficiencies assumed in our case of 2200-volt, 60-cycle motor-generator sets, thereby bringing the total efficiency of the direct-current system much closer to the alternating-current systems. To bear out this point we may compare the relative amount of cable investment per kilowatt, maximum load at generating station for two large companies, one distributing direct current and the other alternating current with distributed transformers. The values, which are based on the pounds of copper in cables and not the cost of cables, are approximately as follows:

	Lbs copper per Kw, Max. Alternating	Direct.
High-tension feeders	114.9	20.5
Low-tension feeders	.....	83.2
Low-tension mains	68.7	67.0
Total	183.6	170.7

If one considers that high-tension cables cost considerably more per pound of copper conductor than low tension cables, it is evident that the comparison would be still more favorable to the direct-current system. This difference is also felt in the maintenance of the system, as even if the life of low-tension and high-tension cables is assumed equal, their scrap value at the time of renewal will be from 25 per cent to 100 per cent lower for the high-tension cables than for the low-tension cables. This will amount to correspondingly higher cost of maintenance of the alternating-current distributing system than for the low-tension system. The higher intrinsic value of the property will also indirectly affect favorably the financial standing of the company, so that it is reasonable to expect that some benefit is derived therefrom in the event of the selling of the property, or in case of making money loans, or even in the market value of the securities issued by the company.

In closing this review of a rather complex and many-sided problem, we cannot omit to at least note the important part played by the storage battery in making the combination of alternating-current and direct-current systems complete and absolutely reliable.

DISCUSSION.

CHAIRMAN LIEB: Mr. Torchio's paper you will note starts out essentially with a number of premises assuming a condition of things which prevails in a large number of our American cities and investigates what should be the future condition, and how such a condition of the property should be handled, with an analysis of the number of systems which could be used to bring about the desired result.

This paper is almost too exhaustive to be discussed superficially, and in order to be discussed in its essential features requires considerable study and investigation. We have a paper which follows along somewhat similar lines, but without special analytical treatment. It is a paper by Mr. Alex Dow of Detroit, entitled "The Direct-Current Distributing Systems of American Cities." This paper follows on somewhat parallel lines, but descriptively, the situation which is outlined by Mr. Torchio more analytically. I will, therefore, ask Mr. W. C. L. Eglin if he will kindly read a brief abstract of the paper, giving us its salient features.

MR. W. C. L. EGLIN: Mr. Dow has treated the subject from a commercial standpoint, and as he states, the most important points are the population and the area covered by direct-current distribution in different cities. He also shows how the bulk of business is taken care of by the employment of sub-stations, instead of by additional generating stations. He makes comparisons later on between the costs of the various devices, particularly comparisons of motors in this country, both direct and alternating, and expects that you gentlemen will make the criticism that we have a higher cost for alternating-current motors than direct-current motors. He lays particular stress on the desirability of using storage batteries on the distributing system, and that it is only practicable with the direct-current system. He argues in favor of a higher regulation obtained by the direct-current system rather than by the alternating-current system. Mr. Dow also believes that there is no advantage to be obtained by using the double voltage recommended some years ago, which was experimented with in some plants in this country, and changed back to the standard voltage. I will read Mr. Dow's conclusions.

THE DIRECT-CURRENT DISTRIBUTING SYSTEMS OF AMERICAN CITIES.

BY ALEX DOW.

(1) The intent of this paper is to describe the electric distribution system which is commonly in use in the central areas of the larger American cities and to state the reasons for the adoption and retention of that system. I approach the subject from the commercial standpoint, taking conditions as they have existed and as they now exist — not as they might exist. In a sense my paper is intended to be a justification of the methods of the larger electric light companies of the United States.

(2) In its essentials the system of distribution which I describe is that which has been employed by the Edison companies of the United States for 20 years past. The independent steam-power district stations of the original Edison plan have in many cases been replaced by sub-stations receiving and transforming power transmitted from a single generating station. The distributing system is thereby affected only in that such a sub-station may be conveniently or profitably placed in a location where a steam plant would be unprofitable or intolerable and that consequently in any given area the number of sub-stations is likely to be greater than the number of steam stations which would have been provided to serve the same area. The general method of distribution, however, stands unchanged.

(3) The Edison distribution system as it exists today is a network of three-wire mains, underground or overhead, supplying continuous current (as we express it, direct current) at constant pressures of approximately 115 and 230 volts from the one system of mains for all purposes for which current can be used. The mains of the system are continuous and interconnected throughout the area to be served. There may be one or more generating stations or sub-stations supplying the same network. Each station or sub-station feeds the network through a number of feeders; the feeders being so proportioned and so regulated as to maintain practically

constant voltage between the several wires of the three-wire system under all conditions of load, while the generated pressure is varied to compensate for the fall of potential in the feeders.

(4) The three-wire method; the interconnected network supplying current at constant pressure; the furnishing of all demands from the same system of mains; the feeder and main method of equalizing the pressure throughout the network — these are now all accepted as standard throughout the world. It must not be forgotten, nevertheless, that in the days of 15 to 20 years ago when electric lighting had its early commercial development in the United States, these methods were Edison methods and Edison methods alone. Today the Edison distribution system has general acceptance and approval, save only in respect of its adhesion to direct current and to a voltage which many engineers think should be doubled.

(5) In preparing this paper I have made no attempt to collect statistics. I have drawn my illustrations primarily from personal knowledge of the distribution systems of several large American cities and where personal knowledge has not been adequate I have obtained specific statements from friends of whose knowledge I am surely advised. To a great extent the statements which I make are familiar to and will be accepted as correct by American electrical engineers. Many of them will indeed to that portion of the audience be truisms, and it is solely because of the international character of this meeting that I have not assumed them to be matters of general knowledge.

(6) In speaking of large cities I have in mind cities of a population of 250,000 or upwards. It is to be noted, however, that what I may call the Edison system of distribution is to be found in many cities of a much smaller population. Generally speaking, that system will be found in any American city which has a well-defined business district. It was in the business and shopping districts as distinguished from the residence and manufacturing districts of our cities that the Edison system had its early development. In these districts only could — at least in the early days of electric lighting — such loads be obtained as would justify the installation of underground mains. In later years with the increasing use of electric light and power, the Edison distribution system has been extended to residence districts and in some cities throughout the entire settled area, these extensions being with underground or

overhead mains as the demand for service, or as municipal regulations, might dictate.

(7) For reference I append a table showing for the eight cities which I mention herein, the population, the municipal area and the area served by Edison distribution.

TABLE I.

	Population Census 1900.	Estimated population 1903-4	Area, sq. miles.	Area served by Edison distribution, sq. miles.
Boston	560,892	600,939	43	3.6
Buffalo	352,387	425,000	51	5
Chicago	1,698,575	2,231,000	190	12
Cleveland	381,768	426,000	33	1.5
Detroit	285,704	317,000	29	3.2
New York (Manhattan).	1,850,093	....	22	15.5
Philadelphia	1,293,697	1,700,000	129.5	3
St. Louis	575,238	612,279	62.5	7.5

NOTE.— The built-up areas outside of the central business district of each city (except Manhattan) have electric supply by alternating currents. The direct-current distribution of Manhattan island covers all the built-up territory of the island. Each city named has within its municipal area much land not yet built on.

(8) The companies using the Edison system do not abjure the alternating current. They use it not only in transmission, but for general distribution in areas where the density of business is not sufficient to warrant the construction of an Edison network. They supply alternating current to motors, both polyphase and single-phase, in these outlying areas. In fact, the so-called Edison companies are among the largest distributors of alternating current for general use.

(9) In the immediately following paragraphs I discuss my subject in detail; noting particularly such points as may be of interest to engineers not familiar with our methods; and stating reasons for our practice where reasons are not obvious or of general knowledge.

(10) *Stations and Sub-stations.*— In the older steam-driven generating stations each engine carries two dynamos connected one on each side of the neutral wire of the three-wire system. These dynamos are shunt-wound and can be regulated by hand for any voltage between the standard pressure of the network and the maxi-

mum pressure required to supply the longest feeder. In stations constructed within the last six or seven years, the pairs of dynamos are usually only sufficient to provide for the balancing of the system and single dynamos of the voltage proper for connection across the outer wires furnish the greater part of the output. It is not customary to depend upon motor sets nor upon a storage battery for balancing but storage batteries are freely used as auxiliary or reserve sources of current and serve incidentally to maintain balanced voltage.

(11) *Battery Sub-stations.*— Sub-stations are in some instances purely storage battery stations in which case the battery is charged from the network by motor-driven boosters during the hours of light load or else through a direct-current tie line from the nearest generating station. A well-known instance of the storage battery substation is the Adams Street station of the Chicago Edison Company where are installed batteries capable of supplying current during the one and one-half hours of daily maximum demand at the rate of 13,500 amperes on each side of the three-wire system. Substations receiving alternating current and transforming it to direct are frequently equipped with storage batteries. This is the standard practice of the New York Edison Company.

(12) *Rotary Converters and Motor Generators.*— The apparatus for transforming alternating current to direct has thus far in the majority of cases been the rotary converter, but there is a large minority preferring and using motor generators. As a rule, those companies whose alternating-current transmission is at 25 cycles use rotary converters for transformation and those other companies whose alternating-current transmission is at 60 cycles prefer motor generators. There are, however, some notable exceptions; as (for instance) the Cleveland Electric Illuminating Company which uses 60-cycle rotary converters, as also do several Pacific coast companies; and the Buffalo General Electric Company which uses motor generators to convert the 25-cycle Niagara supply. The most common size of converter or of motor generator set is probably 500 kilowatts, but larger units are in use and are growing in favor. The standard rotary converter of the New York Edison Company has a capacity of 1000 kilowatts and one machine recently put in service by that company and others now being manufactured for it have a capacity of 2500 kilowatts without exceeding a safe temperature. The Buffalo General Electric Company has had a motor generator set of

1000-kw capacity in service for three years. The Edison Company of Detroit has three motor-generator sets of 1000-kw capacity in service and three others being built. When motor generators are used, the transmission voltage is supplied to the motors without reduction, and the choice between the synchronous motor and the induction motor is usually in favor of the synchronous machine; but there are also a large number of induction sets of the average size. All the small sets — say below 250 kilowatts — have induction motors, and at least one set having an induction motor of 1000 kilowatts is in regular and satisfactory service. I have thought it well to call attention to the use of motor-generator sets because there appears to be among our European correspondents the impression that American engineers are definitely committed to the rotary converter for all uses, whereas it is only in railway work that the rotary converter can be said to be the accepted thing. The lighting companies of Boston, Buffalo and Detroit use motor generators exclusively and the Philadelphia company uses them along with rotary converters.

(13) Balancing between the two sides of the three-wire system is obtained in sub-stations as in steam stations by the use of pairs of generators. Rotary converters connected across the outer wires have the neutral of their transformer system connected to the neutral wire of the three-wire mains. When there are numerous sub-stations on the same network it is obviously not necessary to install a balancing set in each sub-station; the less so when batteries are installed.

(14) *Multiplication of Sub-stations.*— The system tends toward the multiplication of sub-stations. As noted in a previous paragraph it is a much more convenient and less expensive matter to build a sub-station and equip it with rotary converters or motor generators than it would be to build and equip a complete steam generating plant. Many sub-stations are now operated as one-watch stations; that is to say, they are operated only during a short period daily, which period is covered by one staff of operators. The staff in a number of instances within my knowledge is reduced to one man. This condition prevails in districts such as residence districts where there is an evening load but no day load; or (to be more precise) where the day load is so small that it can be supplied through the network from distant generating stations. A similar condition obtains in the office building and wholesale districts of the larger cities where there is a heavy daylight and early evening

load and little or no load during the night. Such sub-stations may be operated by two eight-hour shifts of men. The duties of employees operating motor generators or battery stations are very simple. These employees are under the control by telephone of the central or district operating chief to whom any question arising in practice is referred and by whom instructions are given in case of accident or emergency requiring unusual action. It follows that the wages paid sub-station operators are not large and that, therefore, there is little or nothing to be gained by the concentration of plant or by the installation of automatic regulators.

(15) Obviously the multiplication of sub-stations means the reduction of the investment in feeders. The network of mains will be the same whether it is served from one station or from several, but the cost of feeders will be much reduced if the service is from several sub-stations instead of from one. In general it pays to increase the number of sub-stations so long as the reduction in cost of feeders will pay for the land and buildings. The depreciation of land and buildings is less than the depreciation of feeders — sufficiently less in many cases to pay the additional wages required by the extra sub-station. This general rule has its obvious limitations. We cannot afford to put up a toy sub-station to save a few thousand dollars investment in cables; but when we are installing converting equipment in 500 kilowatt or 1000-kw units, the cost of land and buildings is a small proportion of the total expense. It is to be remembered also that it is not necessary to carry complete reserve equipment in each sub-station. Any sub-station can by raising the generating pressure force current through the network into the area normally served by an adjacent station.

(16) *Regulation of Pressure.*— Pressure wires led back from feeding points are used to indicate in the station or sub-stations the pressure maintained on the system. The regulation is performed by a switchboard attendant. Neither automatic regulating devices nor the compound winding of generators have been approved by the Edison companies. The switch gear is so arranged that separate groups of feeders may be connected to separate generators or banks of generators. The longer or heavier loaded feeders are thus connected to and served by a generator which is operated at a higher pressure than that required by the shorter or less lightly loaded feeders. In some stations provision is made for as many as five groups of feeders. Obviously all the generators are in parallel with one another through the network although not directly connected in

parallel at the station, and the division of load between the generators is accomplished in the usual way by increase or decrease of field strength. The variation of field strength sufficient to cause the generator operating any group of feeders to take its proper share of the load is not sufficient to cause any material variation of the pressure in the network. This method of grouping feeders, together with the customary proper adjustment of the cross-section of each feeder to its length and load, provides sufficiently for ordinary equalization of pressure throughout the network. Rotary converters are, of course, regulated by induction regulators or by variable ratio transformers — not by variation of field.

(17) *Distributing Network.*— The network itself may be either overhead or underground, but in all cities of the first class the mains in the central districts have been underground from the beginning. In small cities and in the less densely populated districts of the large cities, overhead mains are customary. There is nothing unusual about the construction of these overhead mains, the methods common for many years in telegraph work being followed. The wires or cables are covered with two or three braids of cotton saturated with ozokerite or some asphaltic compound, the covering being intended for the convenience of the erecting and maintenance men rather than as an insulation. In dry weather these braided wires carrying currents of comparatively low potential can be handled or laid on the earth or even swung together without making trouble, whereas bare wires cannot be so dealt with and would require much greater care in handling. The neutral wire of the network, whether overhead or underground, is always connected to earth. This has been customary for 10 years past.

(18) *Underground Conductors.*— The Edison tube is still in use as a distributing main. It is likely to continue in use for many years to come. As manufactured during the last 10 years it has proved to be a reliable and convenient form of conductor. The only radical difference between the older and newer form of Edison three-wire tube is that in the new tube more space is left for insulating compound around the coppers. Tubes of 2 in. internal diameter containing three 200,000 circular mil (.157 sq. in.) coppers, and tubes of 2 1/2 ins. internal diameter containing three coppers either of 350,000 circular mils (.275 sq. in.) or of 500,000 circular mils (.393 sq. in.) are the sizes in most common use. When larger carrying capacities are required in the one main it is now customary to employ cables, such cable mains and all feeders laid in recent

years being usually of paper insulated and lead covered cable drawn into vitrified tile ducts. There is in service much cable laid "solid," but the solid method is not now approved. The "draw-in" method has been found not only more convenient but cheaper.

(19) *Fusible Links.*— The connections between sections of the underground network are fusible links of sheet copper of such dimensions that they will fuse at twice the "overload rating" of the mains they are intended to protect. The overload rating is the current which the main will carry for a short period — say two hours — before it attains an unsafe temperature. This is a much greater current than could be continuously carried. The copper fuse link has a considerable time constant — four or five seconds — and obviously it will not be melted by any momentary overload. Neither will it be melted by the extra current flowing when the failure of a feeder causes the supply of a district to reach it through adjacent mains instead of by the normal course. But the copper link melts promptly in case of a short-circuit between the conductors of the underground system, and that is all that is expected of it. In practice a fault in the mains is either burned off, or "blown loose" by the melting of the fuses connecting that particular length of mains to the network. A fault in a feeder is usually dealt with by the operator pulling the switch at the station. The return current from the system then melts the fuse at the distant end of the feeder. These links are a convenient means of disconnecting sections of mains for testing or during repairs. Similar links are used to some extent on overhead mains, but it is much more common to connect up the overhead network without fuses. It goes without saying that every service into the premises of a customer has fuses at the entrance point.

(20) *Direct Current.*— Distribution at constant pressure is universally accepted. Distribution of direct current is, however, an Edison practice much criticised or challenged in the past and present by engineers who believe in alternating current. In later years when transmission by alternating current is so frequently combined with distribution of direct current the challenge usually takes the form of a query as to what justification there can be for the expense of converting machinery requiring sub-stations and attendance for its housing and care. The challengers assume or state that alternating current will meet all practical demands and that, therefore, its conversion to direct current requires needless investment

and needless operating expense. That is an assumption which I will discuss later.

(21) The immediate justification of our adoption of direct current is historical and commercial rather than technical. Nevertheless the technical justification is in itself sufficient and seems likely to continue sufficient for several years to come.

(22) *Historical.*—I give first the historical justification. It is that our industry obtained its first great development in the years 1885 to 1890. Before that time and during that time the Edison system was the only complete practical system of distribution known to the art of electric lighting. By 1885 the system had been developed in all its essentials. Generators which would operate in multiple, the feeder and main system, three-wire mains, distribution at constant pressure, practical underground conductors, practical incandescent lamps of high resistance, practical motors — all of these were found in the Edison system *and nowhere else.* By 1890 this condition was not materially changed. During the years 1885 to 1890 the alternating-current dynamo and the alternating-current transformer were assuming their practical form. Not until 1890 could it be said that they were satisfactory operative devices. It is well to have this fact firmly impressed upon your minds — that many thousand kilowatts of direct-current central station machinery and of direct-current motors still in regular and efficient service were in service before the alternating-current transformer could be deemed a practical and reliable device.

The advocate today of alternating currents has in the alternating-current transformer of today a most efficient and reliable piece of apparatus; but the engineer who as late as 1890 dispassionately considered the possibilities of alternating-current transmission was compelled to recognize in the transformer of that day the weak point of his system — weak both in respect of reliability and of efficiency. And when he turned to consider arc lamps and motors he found himself compelled to admit that alternating arc lamps were impracticable and alternating motors were non-existent.

(23) *Commercial.*—From the commercial point of view the adoption of direct-current distribution was warranted in the beginning by the fact that the capitalist who desired to invest his funds in an electric lighting enterprise could obtain an operative direct-current system complete in all its details from the generating plant to the last translating device without engaging in any experiment,

and with a positive certainty as to the operative efficiency and a reasonable certainty as to the extent of the repair bill. The capitalist who invested in direct-current central station apparatus in the early days of the industry usually made money. The capitalist who invested in alternating-current apparatus almost invariably lost money. That this was due to any inherent difference between direct and alternating current is not to be understood by us as engineers, but that such was the understanding or belief of many of the men who supplied the money for the early electric-light stations is a fact still vividly impressed upon the memories of some of us. The truth of the matter was that in municipal areas where the conditions predicated the installation of an early Edison system there was likely to be sufficient business to make the installation profitable. An exactly similar district *might* have supported an alternating station equally well, but the direct-current men were first in the field and pre-empted all the best locations. Alternating-current men, imbued with belief in the long-distance capabilities of their system, too often undertook commercial impossibilities.

(24) It is necessary in recalling the causes which led to the commercial success of the Edison companies to recognize the effect of the establishment among them almost from the beginning of a uniform system of accounts and reports[1] and of arrangements for the confidential distribution and exchange of practical information. The system of accounts, although far from complete, served for the making of intelligent comparisons. The correspondence between different companies and the meetings held for educational purposes built up a community of interest which has continued in an active and useful form to the present day. The commercial value of this community of interest — of personal and technical, not financial interest — has been and continues to be very great. That it existed in the beginning only among the so-called Edison companies tended materially toward the permanent establishment of direct-current distribution throughout the United States.

(25) *The Persistence of Direct-Current Distribution.*— The reasons for the persistence of the use of direct current are not merely commercial, but are technical. The immediate and obvious commercial reason is that the existing investment in direct-current apparatus is so great that only some tremendous advantage to

1. It was Mr. Thomas A. Edison, personally, and in the beginning, who pointed out the engineering value of a uniform system of accounts and reports for all stations.

be gained by a change — an advantage very much greater than the most extreme advocates of alternating current have yet suggested — could possibly warrant the wiping out of our present equipment. That equipment includes not only our central station machinery but the immense investment of our customers in motors and the investment made both by our customers and ourselves in arc lamps. How great these investments are must be obvious even to our most recent visitor. It is well, perhaps, to give some idea of the investment in direct-current motors which, scattered around in customers' premises, are not so apparent to a chance visitor. On the Island of Manhattan, for instance, there are connected to direct-current distributing circuits approximately 15,000 motors, having a capacity of 85,072 horse-power. In the direct-current area of Chicago the connection is over 9000 motors, having a capacity of 43,230 horse-power. In the comparatively small city of Detroit the connection is 872 motors of 4541 horse-power. You will note that the average horse-power is small. You will please also understand that this connection does not include fan motors, dental motors and similar little machines. It includes only motors of one-half horse-power and upwards. The expense of substituting alternating-current machines for these direct-current machines would have to be borne by the electric-light company. The customers would not stand it.

(26) Another commercial consideration is that our new alternating construction would cost but little less than direct-current construction. Our generating equipment would not be altered in cost. Our equipment of motor generators or rotary converters would, of course, be replaced by transformers and there we would have a material saving; but the motor equipment hereafter sold to our customers would cost more, as also would arc lamps. In respect of meters we would, because of our ordinary use of the Thomson integrating wattmeter for direct-current service, save some money. The induction type of meter for alternating currents is cheaper both in manufacturing cost and selling price and better maintains its initial accuracy of registration. The present difference in cost of arc lamps is considerable. A cheap but practical direct-current arc lamp costs less than $10. A similar alternating lamp costs approximately $13. The same ratio obtains between the cost of direct and alternating arc lamps of the better qualities. As to the difference in cost of motors, I think that is well shown by

Table II, in which I show actual prices quoted on a recent purchase of motors. The motors priced are of similar workmanship and efficiencies.

TABLE II.

Motors sold to .... Company, to be connected to direct-current circuit at .... Avenue.

1 65-hp, direct-current motor, 220 volts,	$722 00
1 20-hp, direct-current motor, 220 volts,	366 00
1 5-hp, direct-current motor, 220 volts,	142 00
Total,	$1,230 00

To equip with 3-phase induction motors would cost:

1 65-hp, 3-phase, alternating-current motor, 220 volts,	$930 00
1 20-hp, 3-phase, alternating-current motor, 220 volts,	635 00
1 5-hp, 3-phase, alternating-current motor, 220 volts,	228 00
Total,	$1,793 00

To use single-phase motors would necessitate using four 15-hp in place of the one 65-hp, and two 10-hp in place of one 20-hp, making the cost:

4 15-hp, single-phase, alternating-current motors,	$1,520 00
2 10-hp, single-phase, alternating-current motors,	610 00
1 5-hp, single-phase, alternating-current motor,	170 00
Total,	$2,300 00

(27) *Shop Cost of Motors.*— At this point I expect to be challenged by some engineer, perhaps one of our European visitors, who will insist that the lower price of the direct-current motor is unnatural and artificial. I admit that the difference in price between direct-current and alternating-current motors is at present greater than is warranted by their respective shop costs. On the other hand, I doubt seriously whether even the polyphase motor — not to say the single-phase motor — will ever be built in American shops at a cost materially less than the direct-current motor. The single-phase motor, afflicted either with a commutator or a condenser, is obviously an expensive machine to make. The polyphase motor, however, with a simple rotor and no commutator may in

time be built as cheaply as the direct-current machine; but it is to be remembered that the two or four or six field coils of the direct-current machine are much simpler propositions in the machine shop and in the winding-room than is the wound stator of the induction motor. The rotor of the induction motor should not cost more than the armature of the direct-current machine. Either motor requires a starting device. The direct-current motor is by long custom equipped with a starting rheostat combined with an automatic disconnecting device. The polyphase motor, if it is to be started without disturbing the regulation of the lighting system, must have either a device for interpolating resistance in the rotor circuit or a variable ratio transformer commonly called a compensator. The cost of either of these is greater than the cost of the exceedingly simple direct-current rheostat. I am inclined to believe that the cost of the commutator and brushes on the direct-current machine will continue to be offset by the greater cost of the stator winding and the starting device of the polyphase motor. Commutators are built cheaply in American motor shops and make very little trouble in operation. This latter statement is true since the adoption of the carbon brush. Our motor inspectors find very little commutator trouble nowadays, and the maintenance of the motor commutator is an exceedingly small item in the expense of operation.

(28) *Alternating Distribution.*— It is claimed by the advocates of alternating distribution that sub-stations are unnecessary if the alternating transformer system is used. In practice we do not find this to be so. We find that while the number of sub-stations may be reduced, yet the requirements of regulation make some sub-stations not only desirable but necessary. It is out of the question to control the distribution throughout a large urban district from one regulating point — the more so if that point be located at a distant generating station. We hear from time to time rumors of this being successfully done but when we follow up those rumors we find either that the load is essentially constant or that the exactness of regulation required is far less than our standard of 2 per cent plus or minus. We do not see our way to change our standard of regulation; neither is it possible for us to modify the load requirements of our urban areas. The variation of load in these areas is so effectively dealt with by our sub-station system that we do not look kindly upon any less effective method.

(29) Moreover, the advocate of alternating current does not nowadays approve of scattered transformers. He used to tell us that transformers might be placed any place, that the space required was negligible, and that the less the length of secondary mains between transformer and translating device the better would be the service. Now we are told that a secondary network is as desirable with alternating current as it is with direct current and that the transformer capacity should be concentrated in as few units as possible. When these units reach the 500 or 1000-kw size (as they certainly must do under our urban conditions) some kind of a sub-station is necessary to hold them and the step from a shelter sub-station to a regulating sub-station is a small one.

(30) *Motors and Arcs.*— There will, therefore, be little or no change in our network nor in our system of feeders. The principal change would be the substitution of large transformers for the motor generators or rotary converters. But when we reach the translating devices there must be radical changes. The difference in cost of motors and in arc lamps has already been noted. The difference in efficiency deserves consideration. That there will be any material difference of motor efficiency does not appear. For equal ultimate cost, over the range of sizes required in a commercial distribution, the efficiency of either type of motor will be practically the same. The amount of light given for equal energy by the alternating arc lamp is probably equal to that given by the direct-current lamp. The steadying resistance of the direct-current lamp can be dispensed with and thereby a considerable saving of energy effected but the character of the light given by the alternating arc is thoroughly unsatisfactory. When the two services are operated side by side, the user invariably demands the direct-current service even when he has to pay for the loss in the steadying resistance. This is not a theory. This is actually a commercial condition and its technical reasons are so well known that I need not state them here. The change of interior illumination from direct-current arcs to alternating-current arcs can practically be accomplished only by making concessions in price to the customer. To change from direct to alternating arcs for exterior illumination is easier but still it is an undertaking requiring much tact.

(31) *Nernst and Incandescent Lamps.*— With Nernst lamps the alternating current has the advantage. In the United States

the Nernst lamp is used solely on alternating circuits, and its experimental use on direct-current circuits has not been a commercial success. The lamp gives good light on direct current but the life of the glower is shortened to an extent which makes a serious difference in the operating cost. Nernst lamps are not yet a large factor in our business although their use is steadily increasing. Incandescent lamps are, of course, equally effective with either direct or alternating current.

(32) *Storage Batteries.*— The storage battery is not a practical auxiliary to an alternating-current system. Its use on such a system requires the interpolation of motor generators or converters having a capacity equal to the maximum output of the battery. The Edison companies of the United States have for years been free users of the storage battery. The number of electric automobiles is constantly increasing. The custom of the owners of electric automobiles is to charge their vehicle batteries from their house supply. Obviously a house supply of alternating current would mean the installation and maintenance of converting apparatus.

(33) *Minor Uses of Direct Current.*— There are a number of minor uses of direct current as in electro-chemical processes, electro-medical apparatus, mercury arcs used by photographers, etc. These uses are not now important but deserve mention. Some of them may become important.

(34) *Regulation Required by Incandescent Lamps.*— In a preceding paragraph (28) I have noted that our rule is to maintain a regulation within 2 per cent plus and minus of the declared voltage. Our practice is somewhat better than our rule. We have learned by experience that the efficiency and durability of incandescent lamps depend mainly upon exact regulation of voltage. I desire to remind our foreign visitors that most of the large American companies own the incandescent lamps used by their customers, and that all of them renew those lamps either free or at a price considerably less than the cost of the lamps. I desire to remind our visitors also that the great majority of our lamps are 16-cp lamps, using 50 watts, the candle-power being in terms of the English standard candle measured horizontally when the lamp is rotated in an upright position. Carbon filament lamps run at the temperature corresponding to the figures just given are sensitive to variations of voltage — blackening rapidly if they are overrun and failing to give satisfactory light if underrun. The

failure to give satisfactory light brings immediate complaints from customers. Overrunning increases rapidly the cost of lamp renewals. Please remember that our custom is to renew a lamp as soon as it is blackened to such an extent as to displease the customer's eye. We do not require that the filament be burned out; in fact some of us so effectively encourage customers to bring in their lamps for renewal that comparatively few lamps are burned out and that the average service of a 16-cp lamp before it is exchanged is little in excess of 400 hours. Our policy in respect to incandescent lamps is dictated by our belief that what our customers expect to purchase from us is light, and that we cannot supply their wants by selling them electric energy and permitting them to select and maintain their own incandescent lamps.

(35) I expect that my statement as to our customary use of lamps having an efficiency of 3.1 watts per candle will be challenged by some of our visitors. I find that my British correspondents are generally incredulous on this point; their incredulity being based upon their own experience rather than upon a knowledge of ours. We have, however, been purchasing lamps sold as of an efficiency of 3.1 watts for 15 years past, and for more than seven years past we have known positively that we got what we purchased. Our present specifications for incandescent lamps — that is to say, the specifications adopted by 60 or 70 of the large lighting companies forming the Edison group and also by several companies outside of that group — require that lamps of a candle-power of 16 and upwards shall have horizontal candle-power at marked voltage of one candle for each 3.1 watts supplied. Under this condition the lamp is required to last in continuous service over 470 hours before its candle-power is reduced by blackening below 80 per cent of the initial candle-power. The specification is filled in practice. That it shall be filled is secured by factory inspection and tests made by a special testing bureau which has been in operation for over seven years. The customary tests include (inter alia) the measurement of watts and candle-power at marked voltage of 5 per cent of all the lamps manufactured for us, the lamps measured being selected at random before they are packed — not from the top of the barrel after packing. Out of this 5 per cent, one-tenth, that is to say, one-half of 1 per cent of the total product, are given a continuous life test, being run at marked voltage until the candle-power has fallen to 80 per cent of its

initial value. The testing organization which I refer to inspected, tested and approved for shipment during the last 12 months for which the records are complete, 5 3/4 millions of lamps of 16 candle-power at 50 watts, in addition to a very considerable number of lamps of higher candle-power and similar efficiency. Nor are the Edison companies the only users of such lamps. There are other users who purchase lamps subject to similar tests; and over and above these inspected and tested lamps there are sales by reputable factories of lamps not similarly tested but made to conform to similar specifications. I have thought it necessary to give these details because so many of my British friends believe a 3.1-lamp to be commercially impossible. It certainly is commercially impossible so long as you leave your customers to buy their own lamps.

(36) The reason for our use of an incandescent lamp of this comparatively high efficiency is our desire to furnish the most light at the lowest cost. We have many times and under many conditions calculated the effect on our investment and on our operating costs of the substitution of a lamp of lower efficiency but the general result is invariably the same; the precise values obtained by the calculation varying only with the minor conditions. Please understand that we recommend and use lamps requiring more current for the same light — that is to say, lamps of lower efficiency — when good regulation is hopeless; as for instance, on circuits where a large proportion of the load is of necessity in the form of motors having unsteady or irregular loads; or where the total work to be done is not sufficient to warrant the cost of good regulation. In our central station practice, however, we have always set reliability of service first; good regulation — that is to say, good quality of service — second, and low operating cost third. And although, as already said, our central station calculations invariably justify the use of the 3.1-watt lamp as giving the most light for the least money spent in fixed charges and operating charges, I am inclined to believe that even if our calculations gave results warranting the use of a lamp of lower efficiency we would still insist for business reasons on the same effective regulation of the light given. A company which gives good steady clear light deserves and can expect a constant growth of its business. A company which offers an inferior service even at a reduced price fails to meet the commercial requirements of American cities.

(37) *Comparative Regulation of Alternating and Direct Systems.*— This discussion of the regulation required by incandescent lamps leads to consideration of the comparative regulation of alternating and direct-current systems. The broad difference between the two is well known to you. The regulation of a direct-current system between dynamo and translating device depends solely upon the resistance of the circuit. The regulation of an alternating-current system depends upon resistance, inductance and power factor of the load. The power factor for incandescent lamps and for Nernst lamps is identical with either current. The power factor for arc lamps and for motors under average central station conditions is very seriously different. A mixed load, supplied through transformers, of incandescent lamps, arc lamps and motors in the proportions common in central-station practice will have a power factor seldom better than .9 and frequently lower than .8. These figures are not theories — they are observations. Please do not forget that these American direct-current central station companies are among the largest distributors of alternating current not only in the United States but in the world. We, therefore, have experience to speak from. Please do not forget either that the motor load in American cities is very large and that the arc lamp load is always respectable. During the evening peak the incandescent lights predominate. At other hours the motor load is likely to be one-half or more of the total service. Our direct-current methods allow us to follow closely by hand regulation the variations of the evening load. The copper which is sufficient to carry without overheating the maximum evening load is amply sufficient to carry without disturbance of pressure the rushes of current due to direct-current elevator motors and similar intermittently operated devices. But that same copper would not be sufficient to take care either of the evening load or of the intermittent service motors if the distribution should be by alternating currents. An increase of at least 10 per cent in copper would be necessary and if the proportion of intermittent service motors were high a still greater increase would be required either in the general network or in the form of a special circuit for intermittent services.

(38) *Elevator Service.*— I suspect that the point of view from which the large American companies regard the elevator motor is not recognized by some of our friends. We do not look upon the elevator motor as an undesirable load, neither as necessarily a dis-

turber of the system. On the contrary we seek to connect so many elevator motors that their individually intermittent operation will provide (because of their number) a continuous load. Momentary loads due to the simultaneous starting of several machines are readily taken care of by the engine fly-wheels. That seems rather a broad statement but it is literally true. I admit that we are liberal in our provision of fly-wheel capacity. When we use batteries of course the batteries take care of these rushes. Our distributing mains are habitually made so large that elevator motors of from 7 to 30 horse-power can be connected without special provisions. The larger motors used for very heavy duties, and the exceedingly rapid acceleration required for the service of the 15 or 20-story office buildings, are almost invariably taken care of by a storage battery located in the same building. We do not offer to supply current for such express elevators unless a local battery is a part of the equipment. Our welcome to the ordinary elevator of the six to ten-story office building or apartment-house is because we recognize in our acceptance of that electric elevator the certainty that the owner of the building will not install his own steam and electric plant but will depend upon the central station service for his requirements of light and power. At this writing the makers of alternating-current elevator motors have not quite succeeded in meeting the requirements of the service. There are many elevators operated from our alternating circuits, but these, unless they are of the smallest size, require a complexity of starting gear which compares badly with the standard direct-current elevator equipment, or the acceleration of the elevator is less than would be acceptable under average conditions.

(39) *Distribution Losses.*—It may be claimed that the loss of energy in the distributing network will be less with an alternating supply than with direct current. I question this; in fact I deny it as regards the great majority of existing distributions. In our present practice we may have a loss between station or sub-station and translating device of 15 per cent during the one or two hours of the evening peak load in the winter months. Fifteen per cent is an exceptionally high figure—virtually a figure which represents the limit of our practice. Ten per cent represents better the ordinary case. With the multiplication of sub-stations this loss is reduced. The condition of maximum loss in transmission obtains only during a total of 200 to 300 hours per annum. Dur-

ing all other hours of the year the transmission loss is but a small fraction of the maximum. All the copper of the network stays in service and at half load the loss is one-quarter of the maximum, and less in the same order for less loads. The annual loss of energy in an Edison network is something like 4 per cent.

(40) The losses in motor generators or rotaries are obviously proportional to the load. As the load decreases the machines are switched out of service; and during the longer periods of light load not only individual machines but entire stations or sub-stations are shut down. Assuming that the transformers required for an alternating distribution are located similarly to the motor generators or rotaries of a direct-current distribution, similar switching would then provide similar economy and the greater efficiency of transformers as compared with converting apparatus would be realized. But if the transformers were scattered over the network and were not switched on and off as required the core losses would in a year amount to at least as large a proportion of the output as the total losses in the direct-current network. Assume 25 per cent load factor and 1 per cent core loss (the latter being 1 per cent of the total transformer capacity) and the core losses are obviously 4 per cent of the output.

(41) *Cost of Generating Apparatus.*— In paragraph (26) I said that our electric generating equipment would not be altered in cost by a change from direct to alternating current. It may be claimed that the generating equipment would be reduced in cost to the extent of the difference in efficiency which exists between transformers and machinery for converting alternating to direct current. This difference might in an extreme case be 10 per cent, and I have been told that to the extent of this 10 per cent of eliminated conversion loss we could reduce the capacity of our generating plant. I don't see it. We might reduce the capacity of our boilers and engines but we could not reduce the capacity of our electric generators, because the capacity of generators — that is to say, their size — is a function of volts $\times$ amperes, not of kilowatts. The power factor of the alternating-current system, .8 to .9, would (and does) require greater capacity in generators to an extent more than sufficient to offset the saving in sub-station losses. Please note that I have said nothing about losses in the regulating apparatus required in sub-stations. When rotary converters are used, the regulating devices employed are substan-

tially identical with those which would be required by sub-station transformers of similar capacity. When motor generators are used, regulation by variation of field strength is all that is requisite.

(42) The ratio of units sold to units generated is a useful figure and deserving of study. But that the ratio is low does not necessarily mean that the commercial efficiency of the system is low. Most of those extra units which look so bad in a comparison between units generated and units sold cost but little to generate — so little that the most precise measurement and analysis are requisite to identify the saving made when we cease to supply some part of them. Thus, the energy to be saved by the substitution in sub-stations of transformers for converters requires for its production but little extra fuel and no extra labor. It is a proportional increase in the output of every hour of the 24. But the possible reduction in fixed charges which would follow the reduction of steam plant, by say 10 per cent, added to the reduction of fixed charges following the substitution of transformers for converters — this total reduction of fixed charges would be well worth having. A calculation made for Detroit conditions shows that the reduction in fixed charges might be 7 per cent — not 7 per cent of the total fixed charges, but 7 per cent of the fixed charges chargeable against direct-current business. This would permit a reduction of 3 1/2 per cent in the selling price of the same amount of energy or might add proportionately to the profits.

(43) *Comparison Between Systems.*— To sum up the case in favor of the distribution of alternating current in our urban districts: The advantages to be obtained are a reduction in the first cost of engines and boilers; a reduction in the cost of sub-station apparatus because of the substitution of transformers for converting machinery; and a longer life for the glowers of Nernst lamps. The disadvantages are inferior regulation of voltage or (as an alternative) greater cost of mains and feeders; inferior arc lighting and greater cost of arc lamps; special contrivances required for charging small storage batteries; and the requirement that to each large storage battery be added converting machinery capable of carrying the maximum discharge of the battery. These advantages and disadvantages seem to be permanent consequences of the difference between the two currents. Temporary disadvantages of the alternating current are the greater cost of constant speed motors and the lack of satisfactory motors for elevator work. I am per-

haps optimistic in terming these motor disabilities "temporary." My conclusion is, after in many specific cases comparing these advantages and disadvantages, that the direct current is at least equal and likely to remain equal to the alternating current in its suitability for general distribution, and over and above its inherent equality it has the immense advantage of prior occupation of the territory. What this means to us as owners or operators of central station properties I have already indicated. What it means to the general consumer in that every device which he is likely to use has been for years standardized for direct current and is manufactured for direct current by a score or a hundred manufacturers, each and all anxious to obtain the consumer's trade — what this means cannot be expressed within the limitations of a paper for this audience. It may be indicated to you by the fact that in every large city of the United States where direct current and alternating current have been offered competitively to the public the direct-current system is today in possession of the business of the central territory.

(44) *The Question of Voltage.*— There remains the question of voltage. In large American cities we have generally adhered to an incandescent lamp voltage under 125 volts and our three-wire systems are arranged to maintain the selected lamp voltages between outers and neutral. Many of our friends in Great Britain and a very few in the United States have undertaken the supply of urban areas with lamps of double the voltage which we use, and have doubled the difference of pressure between neutral and outer wires of the three-wire system. The reasons for our practice in this respect are (as in respect of our adherence to direct current) both commercial and technical. Technically, our main reason is that there is not made a double voltage incandescent lamp of an acceptable efficiency and life. To use an incandescent lamp of lower efficiency would mean the reduction of the earning capacity of our present networks and generating apparatus; or, conversely, would mean that we would require a greater capacity in generators and mains to do the same amount of business. Another technical reason is the inferiority of the double-voltage arc lamp. We formerly used two arc lamps in series. We welcomed the advent of the enclosed arc with its higher voltage because (among other reasons) it allowed us to get rid of these series lamps. Such series arc lamps, moreover, cost more than single lamps and are likely to continue to

cost more. The high-voltage motor — that is to say, the 440–500-volt motor — is a more expensive machine to build and costs more in the market than the motor of 220–250 volts — that is to say, it is so in the average sizes used by our customers. Moreover, it tends to have commutator troubles, from which the 220-volt motor is notably free. The insulation which must be maintained for double voltage is markedly greater than that which is permissible at the present voltage. Moreover, our practice of handling our mains alive — making connections and disconnections and minor repairs — would have to be changed if we carried twice the present pressure. Our customers' meters are all watt-hour meters having a potential circuit connected across the mains. In three-wire meters the potential circuit is connected from one outer to the neutral wire. The loss of energy in this potential circuit is as great as we are willing to accept and we do not take kindly to the idea of doubling it. Of course, we could use ampere-hour meters as do so many of our British friends and thereby do away with all losses in potential circuits, but to do so would be to get out of the frying-pan into the fire. We would in that case in doubling the voltage double the "slip"— that is to say, we would double the amount of energy passing through the consumer's meter unregistered.

(45) *Incandescent Lamps of Double Voltage.*—The proposed use of double voltage incandescent lamps deserves special discussion. In preceding paragraphs (34 to 36) I have recited our practice in respect to ownership of incandescent lamps, and renewal of lamps blackened or burned out in service. Under our present conditions, for each kw-hour sold to customers for use in incandescent lamps, our expense for lamp renewals is between .3 cent and .4 cent. The difference between these two figures is due to the varying practice of different companies — not to any appreciable difference in voltage regulation in different cities. Three-tenths of a cent represents the lowest expense at which customers can be satisfied. Four-tenths of a cent represents service at a high standard when the customer is encouraged to renew his lamps frequently. Taking either figure, it is obvious that lamp renewals form a large proportion of our operating costs — after fuel, the lamp renewals are the heaviest single item. Taking the figure given in paragraph (35) of five and three-quarter millions 50-watt, 16-cp lamps — with the further statement that the Testing Bureau referred to in that

paragraph inspected during a recent 12 months for use on our systems of distribution over 10,000,000 incandescent lamps of all kinds — it will appear to you that a reduction in the effective life of incandescent lamps would be to us a very serious matter.

(46) We have studied and experimented with the double-voltage lamp for many years. It is at least seven years since we made our first earnest effort to utilize it, and during the seven years more than one experiment on a large scale has been made by us. In addition to our experimental central station work there have been many commercially successful installations of double-voltage lamps in the United States, and such installations are increasing. These commercial installations have been under conditions where lower lamp economy was permissible and where a reasonable life could, therefore, be obtained by the use of a lamp of 3.6 to 4 watts per candle. It will appear from the foregoing that we do not speak without knowledge. I may say to our British friends that our knowledge includes a respectable acquaintance with double-voltage lamps manufactured for the British market both by British and continental makers. Our conclusion always has been that we could not under present conditions afford to double our standard voltage. Our further conclusion has been that the differences between standard voltage and double-voltage lamps were inherent in the nature of a carbon filament, and not to be done away with by improved manufacturing methods. So far as we can foresee we will always have the choice between a greater investment in distributing mains with the use of lamps of a superior efficiency, and a reduced investment in distributing mains with lamps of inferior efficiency. The alternative of shorter life of the lamp is not acceptable; for the reason (over and above its increased cost to us) that we cannot require our customers to make exchanges more frequently than they do now. We find that shorter lamp life brings complaints. Even when the exchange of a lamp is not inconvenient — that is to say, when it is not located in some practically inaccessible position, say a dressed show-window, customers will complain if they have to change lamps too frequently. It is not the expense they object to. The expense falls on the company. It is merely the trouble of making the exehange.

(47) So far I have spoken particularly of lamps of 16 and greater candle-power. But a large and increasing part of our business is decorative and sign lighting which requires lamps of two candle-

power and four candle-power. This is profitable business because of the long hours of service. The lamps are of lower efficiency than lamps used in regular lighting, our custom being in such work to reduce the efficiency of the lamps until the cost per kw-hour for renewals is approximated to the average. Double-voltage lamps of these candle-powers are simply impossible. They can be made. They have been made for us, but the cost of manufacture is prohibitive. A lamp of short life will not serve. The extinction of a few lamps spoils the decorative effect and the replacement of lamps in signs or displays is always relatively inconvenient. And a lamp of very low efficiency would put the cost of energy up to a figure beyond what the business will stand.

(48) *Double-voltage Comparisons.*— What are we to gain, then? Reduced cost of mains and feeders or alternatively a much longer radius of distribution from each station or sub-station and thereby a reduced number of stations. That is about all. Our regulation is now excellent — we do not need double voltage to keep our lamps up to candle-power. Our losses in transmission are now so small that their reduction will not warrant any great investment. And the reduction in cost of mains is merely a reduction in copper, obtained at some expense for additional insulation if the former factor of safety is to be retained. As between copper and insulation we would rather lock up money in copper. It is one of the very few things we buy which does not deteriorate. The reduction of the number of sub-stations means some saving in buildings, but nothing in machinery and only a trifle in labor. Per contra to these gains we shall have a serious reduction in the earning capacity of our machinery, the reduction being measured by the additional capacity necessary to illuminate the double-voltage incandescent lamp. And the capital expended in changes of lamps, both arc and incandescent, in changes or reconstruction of generators and motors, and in minor changes of customers' house wiring, would be a clear loss. We so far have never been able to figure a profit in the change. On the contrary, one of the most notable double-voltage installations in the United States, that of the former Imperial Electric Company of St. Louis, is about to be changed over to standard voltage.

(49) *Concerning Underground Mains and Double Voltage.*— It goes without saying that each central station has its own local conditions and that no one rule, nor even the frequent demonstration of that rule, can settle such a question as this for any case not

specifically calculated. Far less does the rule or practice of one country settle the question for another. On the contrary, local conditions which obtain in one country and not in another may justify many radical differences in practice. I think I have recognized in British practice a well-established cause for the acceptance of double voltage — to-wit, the relatively great ratio of cost of mains to total investment. This ratio is occasionally such as to control the engineering of the entire plant. It is not so with us. Not only is the relative cost of mains small because of our liberal use of overhead wires, but also because our methods of underground construction are comparatively cheap, and because with us the proportion of copper cost to total mains cost is large. Our ordinary paper insulated lead-covered feeder cable has in it 50 per cent to 60 per cent of copper value, only 40 per cent to 50 per cent standing for insulation and lead covering. The tile duct into which we pull a pair or three cables costs us complete (including manholes) 16 cents to 30 cents per duct foot. Sixteen cents represents recent trunk line work with 20 to 30 ducts in the run. Thirty cents per duct foot represents the cost of branch runs or runs laid in streets where obstacles are numerous and labor cost goes high. Even the self-contained Edison tube with its complex provisions for flexibility and for frequent service connections is completed in place at a reasonable cost. Wherefore a reduced expense for mains (or rather a reduced investment in copper) does not tempt us as it might a British engineer whose underground constructions (possibly of necessity) required the major part of his capital expenditure. Moreover we have (the most of us) been foreseeing in the matter of conduits. When we opened a ditch wherein to lay three immediately required ducts we have laid nine more to provide for the future, and we have profited by the foresight. To lay an additional feeder in such circumstances is not only simple but comparatively inexpensive. If it meant the tearing up anew of streets paved on concrete foundations or if it meant when it was completed that our new investment would stand 20 cents for copper and 80 cents for insulation and laying down it may be that we would look more favorably upon the double-voltage expedient.

(50) *In Conclusion.*—It is necessary to omit from a paper of this class the discussion of many minor but interesting technical matters. I have limited myself to the salient features of that central station practice which I proposed to describe and discuss. It

would be profitable to consider also some of the conditions beyond the boundaries of electrical engineering which have affected the evolution of our Edison lighting systems — for instance the comparative price of gas, the common use of elevators, the demand for a bright light which has made the 16-cp lamp our standard, and the toleration of overhead wires in all but the most densely settled areas. It would likewise be profitable to consider the business and manufacturing methods of our people which caused them to welcome the electric motor when it was first offered and by reason of which supply to electric motors in many cases is now half the output of a station and one-quarter to one-third of the station's earnings. These considerations, external to electrical engineering, have been potent in the evolution and differentiation of our distribution methods and if it were our present affair to determine to the ultimate limit why American central station engineers have done those things which are recognized as distinctly American we should find it necessary to give full consideration and weight to these and to many kindred causes. This present paper has now, however, covered the ground it was proposed to cover and reached its intended conclusion.

Chairman Lieb: Before taking up Mr. Gotthold Stern's paper on the "Superiority of Alternating Current for the Supply of Current to Large Cities," I will make a few remarks which will perhaps serve as an introduction to Dr. Stern's paper. When the program for this section was in course of preparation, we had submitted to it suggestions for these two direct-current papers. I corresponded with a number of friends, who I felt would undertake a presentation of that side of the question, and I finally enlisted Dr. Stern's interest in the matter. I will ask Mr. Arthur Williams if he will be kind enough to read Dr. Stern's paper, after which we will have a joint discussion of the papers of Mr. Torchio, Mr. Dow, and Dr. Stern, as they cover practically the same ground.

Mr. Williams read Dr. Stern's paper.

THE SUPERIORITY OF ALTERNATING CURRENT FOR THE SUPPLY OF CURRENT TO LARGE CITIES.

BY DR. GOTTHOLD STERN.

In order to define the above proposition accurately from the start, I desire to state in advance that I have undertaken to demonstrate in what follows that for large cities the form of current which is best adapted in the present state of the art is the alternating current, and that this is the case not only with regard to generation and transmission, but also for distribution and delivery to the consumer. We mean alternating current in the broad sense of the word, including also the polyphase forms of current.

My proposition divides itself naturally into two parts: First, in which form of current the unit (kw-hour) can be supplied by the producer at the lowest price; and secondly, in which form of current the unit is of most value to the consumer.

We have, therefore, to decide first, which is the cheaper to produce, measured at the customer's meter in a large city, a kw-hour of direct current, or a kw-hour of alternating current.

The production of direct current by steam-driven dynamos, in large cities, requires only short treatment in view of our experience to date. The necessity of subdividing the service between several smaller central stations built on expensive real estate and the difficulty of supplying them with coal and water in the midst of streets crowded with traffic, has led all modern electrical engineers to abandon this oldest method of current supply, even such as, until recent years, wished to have nothing whatever to do with alternating current.

Moreover, direct-current dynamos cannot be constructed of the capacities now required by large central stations, and such direct-current stations are, therefore, equipped with a number of smaller units. Very few of the direct-current dynamos in Europe have a capacity greater than 1000 kilowatts; the average capacity of the dynamos in operation in the largest 15 Continental direct-current

stations is 320 kilowatts. It is evident that steam engines adopted to such capacities are far from being as economical as larger units of the same quality; moreover, the labor required by a number of smaller units is greater, their first cost is higher and the space required greater.

It will be contended that smaller units could be *apportioned* more readily to the variable load created by the varying demand on an electric-light station; but on drawing the load curves (Fig. 1) of a characteristic summer and winter's day and circumscribing them by a broken-line diagram indicating the units in operation, it is

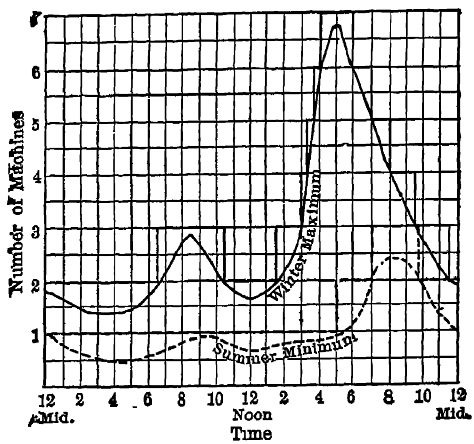


FIG. 1.—SUMMER AND WINTER LOAD CURVES.

evident at once that even in the largest stations a sufficient relation between engines in operation and the load on the station can be secured by 6 to 8 units, including the reserve; this number is still further diminished in the case of direct current if the load is equalized to a certain extent by batteries. Practically, therefore, in stations of the same size, direct-current dynamos should be selected in units, of even larger capacities than alternators. However, in spite of this requirement, difficulties in manufacture of direct-current units of large size compel the selection, in a large city, of direct-current dynamo units of a smaller capacity than would be dictated by the selection of the most favorable size of unit.

In the present period of transition to the steam turbine there is added another difficulty. At the high rotative speeds of these

turbines there results such a high number of pole reversals in the case of direct-current dynamos as to make commutation extremely difficult. It is difficult enough to construct the commutator with sufficient safety mechanically for the high speeds, and the tendency to sparking is greatly increased at the higher differences of potential resulting from the higher number of pole reversals between adjacent commutator bars. The wear on the commutator and the brushes is enormous, and although methods have been suggested for eliminating the sparking by special windings, this difficulty will always stand in the way of the application of large direct-current dynamos to steam turbines.

Some of the lesser difficulties in the station incidental to direct-current working need not even be cited in the comparison. We shall, for instance, ignore the difficulty of handling the direct-current commutator in contrast with the ease of maintenance of the contact rings of the alternator.

We must not forget, however, that alternating-current working has also its inconvenience; the separate exciter in the case of the alternating-current generator is a certain complication, and the paralleling of alternators undoubtedly requires somewhat more practice than paralleling of direct-current dynamos.

Finally, we must not leave out of consideration the advantages inherent in the direct current in connection with the possibility of its storage in storage batteries. If this possibility were coupled with smaller losses and if storage batteries had greater durability, there would be established a preference which for many purposes would outweigh many other disadvantages. Unfortunately, however, both conditions have not been fulfilled. The real purpose of a storage battery should consist in changing the variable load on the central station machinery to a more uniform load, i. e., to almost integrate the daily load curve. We should then reach a steady loading of the engines and boilers and they would operate continually at highest efficiency. The increased safety attained by the application of storage batteries is certainly very valuable as the batteries can take up at once the supply of current should an accident occur to the machinery.

But with what losses and costs is coupled the operation of storage batteries! It appears from statistics of the "Association of Central Stations" in Germany that in cities with a population of over 200,000, in which storage batteries are used, the losses occurring in

the batteries amount on the average to 33.5 per cent. The first cost of the storage batteries for each kw-hour supplied through them amounts to 98 pfs. (24.5 cts.), and as interest and depreciation at the longest life of the cells — 10 years — must be reckoned as at least 15 per cent per annum, they increase enormously the cost of the current passing through them. If the cost of production of the kw-hour at the dynamo terminals be 10 pfs. (2.5 cts.), it is increased by the losses in the storage batteries to 13.35 pfs. (3.337 cts.); and on account of interest and depreciation on the invested capital by 14.7 pfs. (3.675 cts.) additional, a total of 28.05 pfs. (7.01 cts.). Of course, the increase of price applies only to that part of the output which has passed through the storage batteries. In the cities above referred to this amounts on the average to 12 per cent of the total energy produced, so that the storage batteries cause an actual increase of 21.6 per cent in the price of the total production of current.

And notwithstanding this, it cannot be denied that storage batteries present a considerable advantage on account of the increased safety and better equalization of the service. This advantage cannot be realized, however, until such time as a good storage battery may be available — a time unfortunately not yet at hand.

The comparison will not be complete if the losses in the transformers are not considered also. The capacity of the transformers in well-planned alternating-current stations is less than the number of connected lamps; their efficiency is up to 99 per cent at full load, and even at half load, and, in good construction, not under 97 per cent. Of course, the iron loss of the transformers is continuous while the transformer is in circuit. This circumstance was formerly considered to be the weakest point in alternating-current service. Under the most unfavorable conditions this loss is calculated about as follows: The total transformer capacity is sufficiently valued at 80 per cent of the connected installation of the station; for 100 kilowatts of connected installation, representing in the station of a large city an annual consumption of 60,000 kw-hours, there would be, therefore, 80 kilowatts of transformers whose iron loss, if of good construction, is about 1 per cent or 0.8 kilowatts. In the whole year there would be a loss in the transformers of 7000 kw-hours, or about 11.7 per cent of the energy consumed. If the proper number of transformers is selected in the sub-stations, and those not required for the demand at the time are cut out of cir-

cuit by hand or by automatic switching apparatus, this loss can be considerably reduced. Apparatus of this kind (made by Schlatter, Scholtes, etc.), has been continually improved from time to time, and it has also given good service for single transformers. The copper loss in good transformers is very small and proportional to the momentary load.

Let it even be admitted that if the e.m.f. which is necessary for distribution were limited to 500 volts, the preference might be given to direct current from the standpoint of current production; notwithstanding that even at this pressure the unrestricted size of the generating units and the free choice of the driving engine and the absence of the commutator are arguments not to be underestimated for alternating-current operation in large central stations. The comparison is changed at once, however, if the ease of utilization of high pressures in the case of alternating current is taken into account.

It is important not only to manufacture the commodity cheaply and of the most satisfactory quality, but it must be transported cheaply and delivered cheaply to the customer at his residence. This is possible only by a rational utilization of the means of transportation, and these in the case of the distribution of electrical energy are the cables. With the large areas covered by our large cities the transmission of the electrical energy can be effected in two ways only: First, the erection at various points in the middle of the city of several smaller stations, conveying the current from them to the points of consumption at comparatively low pressure through heavy cables; or, second, proceeding from one or two large stations carefully selected as to location for the most favorable construction and operating conditions and conducting the electric current into the city at high pressures through comparatively small cables.

In the case of a large city with a diameter of about 5 km (3.1 miles), if it is desired to limit oneself to a single station — and it is desirable to do this for many reasons — it becomes necessary to use high tension, to avoid the expenditure of unheard-of sums for copper conductors, and the enormous loss of energy in the cable network. If some measure of importance is attached to uniformity in the pressure furnished to the consumer, the demonstration of this statement by actual figures need hardly be required at this time.

Direct current can hardly be seriously considered for high tension: First, because it is almost impossible to maintain high-tension, direct-current dynamos in operating condition; secondly, because high-tension direct current can be transmitted by cables only with great difficulty, and thirdly, because the pressure of direct current can only be converted by rotating machinery.

Alternators, on the contrary, can be safely built for almost any desired high tension, the leading away of the current not presenting any difficulties, because the high-tension windings can be applied in the simplest manner to the parts of the machine at rest, and, therefore, not subject to displacement and the resulting strains.

Operating at the same pressure, conductors for alternating current are superior to those for direct current as regards safety and durability, for in the case of direct current in addition to the e.m.f., which constantly tries to effect an equalization between the conductors of different potential thereby tending to break down the insulation, there is added thereto the electrolytic effect which exerts a destructive action, not only on the conductors but under certain conditions on neighboring metal parts also. This is particularly the case with underground cables, and probably no manufacturer has yet given a guarantee for an underground cable for direct current over 1000 volts.

As a matter of fact, cables which have been underground approximately 15 years subjected to 2000 volts alternating current are not noticeably affected, as shown by lengths of cable in the Vienna cable system. If the proper choice has been made as to the type and thickness of the insulation, only chemical influences have had an effect on them as in places where the earth shows the presence of acids (under horse-stands, and in the neighborhood of cesspools) the lead sheathing if often attacked. Of the Vienna 2000-volt alternating-current network which was begun in 1889, which had 75 km (46.4 miles) in 1892 and to date has increased up to 400 km (248 miles), there have been replaced during the whole time only 340 meters (1120 ft.), or less than 1 per cent on account of failures, and the insulation resistance per kilometer has the same value today as at the time it was laid. Of course, failures in the cable network occur also with alternating current due to mechanical injury, etc., and we shall examine now the manner in which these show themselves. For simplicity's sake, let us consider a two-wire system.

If one of the alternating-current conductors is damaged at one point, so as to ground there, the service is in no way affected; even a second damage to the same conductor, by which a part of the current finds a return path through the earth, is without any particular harmful effect.

With direct current, on the contrary, the passage of the current to earth gives rise to an electrolytic action, which not only destroys in a short time long stretches of the conductor itself and its metallic sheathing, but also causes serious chemical decomposition in its passage from the metal parts of water and gaspipes, street-car rails, etc. If the second conductor also is completely earthed, a short-circuit results, which, in the case of direct, as well as alternating current, can be productive of disastrous consequences, if provision is not made for switching off at the right time by properly proportioned safety catches. It is different with the sneaking grounds when there is no complete earthing, but only a lowering of the resistance. In this case also with a defect on one pole, a part of the current is diverted through the earth, and but a few amperes of direct current, which are thus shunted around the cable, cause an electrolytic action, which results in damage to the whole length of the cable from the beginning of the first fault to the end of the last.

If a sneaking fault of this kind appears on both poles, it has frequently happened in the case of direct current that one of the conductors was completely destroyed over a considerable length, if, indeed, the heavier current had not previously completely fused the piece of cable, already reduced in its cross-section. An alternating-current net-work, even for high-tension current, is not in the least affected by grounds in a single pole even if they appear in considerable lengths and at different points; in failures on both poles no serious results are experienced at first until the current has found the weakest point of the faulty piece and caused a complete break-down at this point. The fault is, however, confined to this one spot, and can easily be repaired by a simple splice. Cable faults are certainly not pleasant with any system, but the practical station operator will prefer the energetic manifestations of break-down in a high-tension alternating-current cable to the lurking danger of the direct-current corrosion.

Alternating-current high-tension cables are, of course, subject to many dangers not present with direct-current cables; there are

break-downs caused by oscillations in pressure which arise with certain relations of self-induction and capacity, favored by the appearance of harmonic waves. Since these phenomena have become better known, it is not so difficult to provide protection against the consequences, and disturbances from these causes are avoided by the application of devices protecting against excessive tension and spark-gaps.

High-tension alternating-current cables are always so constructed that the several conductors are inclosed under the same sheath and iron armor. This is necessary to avoid inductive effects. This is readily possible only because comparatively small copper sections are necessary. In this way self-induction in the cables is prevented and there is also no disturbing effect to neighboring telephone and telegraph wires. The absence of lurking defects in insulation in the case of high-tension cables, and the small currents carried by them, prevent telephone disturbances from stray currents, and these occur with much less frequency than with low-pressure conductors as used for direct current.

In addition, the alternating current has an inherent characteristic, by which the high tension at which it can be generated can readily be practically utilized, i. e., the possibility of conversion in transformers. Not until this characteristic became a practical possibility through the efforts of Zipernowsky, Dèri and Blathy, could the alternating current begin to conquer its territory.

It is, of course, also practicable, in the case of alternating current, to transform from high tension to the distributing voltage by rotary converters, and many large stations convert the high-tension alternating current into direct current of the pressure to be delivered to the customers.

The opponents of alternating current give as a ground for this conversion that the alternating current cannot perform equally as good service as the direct current, the correctness of which assertion we shall test later on.

What then could possibly induce them to prefer the operation of sub-stations with machines, apparatus and expensive attendance to the installation of transformers which require no attention and are more economical in operation and cheaper in first cost? If there were not an enormous difference in the quality of the two currents and their utilization on the part of the consumer which would determine the preference, the reason for this conversion into direct current could be explained only by the possibility of utilizing the older

direct-current stations (whose operation as steam-generating stations had been discontinued) as sub-stations operated from a large alternating-current station, and utilizing as far as possible the existing equipment. The advantages of transformers as compared with rotary converters are so numerous that they could not be left out of consideration on other grounds. First, their cost is about one-half; secondly, the weight of a 100-kw transformer is only .6 the weight of a rotary converter of the same capacity and .4 that of a motor-generator of the same capacity, quite aside from the fact that often in the case of motor-generators — and always in the case of rotary converters — transformers are required in addition.

Transformers require no constant attendance; they occupy less space and their efficiency is higher. It is not difficult to construct transformers having 99 per cent efficiency. Rotary converters with over 95 per cent efficiency have probably not been constructed, and at partial loads the difference in favor of transformers increases, especially if the comparison is made between smaller types.

All of these circumstances lead to the fact that it is possible with transformers to increase notably the number of sub-stations without sacrifice in economy of cost of installation or of operating. In such cases the sub-stations supply only a small area of the city, and the influence this has upon the cost of the secondary network is clearly apparent.

In the case of rotary-converter installations, in order to secure larger units and a smaller operating force, and because it is difficult to obtain suitable real estate for sub-stations, it is desirable to limit the sub-stations to the smallest possible number; the primary circuits are in consequence somewhat shorter, but the increased cost of the secondary network is many times this saving.

It is desirable then to select as high a secondary pressure as possible, delivering to the consumer by a three-wire system of 2×200 volts or even 2×250 volts, not forgetting, however, that by so doing the mistake which it is desired to avoid becomes emphasized — the delivery to the consumer of a less valuable kind of current.

We have now touched upon the second question which I advanced: Which kind of current is of more value to the consumer? In connection with the house wiring there appears at once a great difference. The same conditions which appear to make the direct-current conductors in the street inferior as regards durability and safety hold in a still higher degree in favor of the alternating current in

residences. The insulation of direct-current house wiring at the same pressure must be better on account of the more severe requirements imposed by the electrolytic effects; they are on this account dearer for the same safety, or at the same installation cost, are less safe. Furthermore, the distributing pressure in the case of direct current must be higher on account of the greater distance between sub-stations, causing an additional difficulty in this direction. Finally, it appears, that on account of the secondary network with widely ramified branches, every lack of insulation at every point either in the street cables or in any house installation, causes an undesirable disturbance in the installation of every consumer connected to the same sub-station. The most desirable from the standpoint of the consumer is, therefore, an alternating-current service with house-to-house transformers at low secondary pressure.

I believe I am not saying too much when I maintain that the consumer will also prefer the alternating-current meter to the direct-current in the long run. Without the commutator or brush contacts common to most direct-current meters, it is a simpler instrument and subject to fewer troubles. The clock meters of the Aron type are constructed for both systems, and the electrolytic meter has been abandoned for many years.

The consumer in a large city uses electricity primarily for lighting and usually with incandescent lamps; arc lamps and motors occupy a second place, and finally we may consider several special applications for medical purposes, etc., which, however, would not determine a preference in the selection of the type of current. After careful reflection I have not put motors in the first place in the consideration of central station service, as is generally the case, and my decision is based upon the following considerations: The price of electric current for motors must be considerably cheaper than for lighting in order to compete successfully with other motive powers. There is really no other reason why central stations sell current for motors so much cheaper than for lighting. The supply of current for electric railways is not here considered because they usually have separate stations. According to the statistics of most of the large cities, the average hours' use of current for motors is not greater than that of current for lighting. During the hours of maximum lighting load in the European continental cities, the motor load does not fall off; in the winter months, in average latitudes, the heavy lighting load begins at 4 o'clock and reaches a maximum at 5 o'clock, but the motor load does not cease until 6 o'clock.

Even the fact that the maximum demand of the current for lighting does not show the same number of average hours' use per year as current for power does not strongly modify this conclusion; for, although it is difficult to obtain exact data on the maximum demand of this or that service, it can be stated with some certainty that current for motors will not show any sensibly better load factor than current for lighting in the large continental cities. There remains but one reason for the cheaper prices for motor current — expediency. Current for lighting must be considered, therefore, as that for which the highest price is paid and from which the station receives the best returns, and should be considered, therefore, as of first importance. The value of power supply should not be left out of sight, however, for it represents about 35 per cent of the connected load in large continental cities, and because it increases the hours of service, although to an extent which is overrated. Furthermore, the distribution of energy is a great national economic advantage in the development of cities, which stations operated by municipalities will not leave out of sight. Although the question as to which form of current is best adapted for motor service should not alone determine the choice of the system, it is, nevertheless, a factor which must be considered. Until several years ago the majority of electrical engineers recognized only the direct-current motor; since the discoveries of Ferraris and Tesla in connection with the concatenation of alternating-current circuits, all this has gradually changed, and today the polyphase motor is no doubt superior to all others. In large cities it is largely a question of application to industries of a character in which the motor will receive but little attention — small factories, private establishments, bakeries, butcher shops, etc., services which require that the motor should operate as soon as the switch is thrown. The commutator is an obstruction for such service; it is often neglected and then gives rise to disturbances; even the rheostat which must be switched in is too complicated.

In the case of the polyphase motor, particularly if for service of this kind it is equipped with short-circuited armature, these difficulties do not appear; it is necessary only to open or close a three-pole switch. The polyphase short-circuited is to be preferred, particularly for service in which the motor receives no attention for long periods. This would be the case also in the application, sought for by central station technologists, of electric motors to the driving of small ice machines which, of simple construction, could be intro-

duced in the large cities in great numbers, giving a welcome summer load for the central stations.

The polyphase motor is of a type which, of all electrical machines, has the least mechanical workmanship, possesses the fewest number of parts subject to wear, requires least repairs, and approaches most nearly the ordinary machine construction. As regards efficiency, it is the equal of the best direct-current type, and produced in quantities its cost of production is less than direct-current motors. Even the constructions with contact rings are characterized by their simplicity as compared with direct-current motors, and possess all of the characteristics through which the shunt direct-current motor secured its extensive introduction for steadiness of running, regulation of speed and large starting torque.

Of late single-phase motors, the shortcomings of which constituted for a long time a hindrance to the extension of the single-phase system, have entered a new stage of development. The series and repulsion motors for alternating current, known for a long time, had the defect that it was hard to prevent sparking at their commutators, and their speed varied considerably with variable load. The types of Lamme, of the Wagner Company, of Dèri, of Finzi, of Eichberg, of Latour and of the General Electric Companv and others, have so far overcome this difficulty that today it is adopted for that most difficult application of the electric motor, the electric railway. It is to be expected that these methods will be still further developed in the near future and that then the single-phase alternating-current system, the simplest of alternating-current systems, will receive the appreciation which it really deserves.

One of the most important applications of the electric motor in large cities is the driving of elevators. In the continental cities of Europe this part of the service is not very lucrative for the central station, as the average use is very small and is contemporaneous with the lighting maximum; however, the elevator service is the best means of securing the introduction of electric lighting in a house. In this service also, the polyphase motor has surpassed the direct-current elevator; it has, like it, a steady speed; it can be arranged for equally large starting torque; it is reversible with equal ease, and much less sensitive as to its windings, which in the case of shunt direct-current motors, particularly for 2 × 200-volt systems in which the motors are wound for 400 volts, are easily burned out by careless switching, and in other respects is subject to greater repairs than the polyphase motor.

There is hardly a service which cannot be undertaken with polyphase motors more rationally and economically than with direct-current motors, and even if the motor service is considered of the greatest importance to the central stations in large cities, the alternating-current supply is to be preferred to direct-current supply in this respect also.

In view of the decisive importance of the incandescent service, that system must in the long run win the victory which presents a superiority for incandescent lamp service. The connected installations of incandescent lamps exceed the connected arc lamps five to one in the European stations.

As regards the utilization of the electric current for incandescent lamps, the two kinds of current have for a long time been considered as of equivalent value. This is really the case at the same pressure; but the fact is becoming more recognized that the filament incandescent lamps are more advantageous at low than high pressures. But the direct-current stations have a tendency, in order to utilize their networks to best advantage, to raise the pressure, while in the case of alternating current, especially with house-to-house transformers, the service pressure can be chosen almost as low as may be desired. The 200-volt incandescent lamp, according to exhaustive tests, consumes 20 per cent more current with the same life, or at the same efficiency it has 30 per cent shorter life than the 100-volt lamp, while the cost is 15 per cent greater. Two-hundred-volt lamps of less than 10 candle-power, or less than 2 1/2 watts per candle-power, cannot be produced as yet. Extensive tests have shown that in order to operate filament incandescent lamps most economically, it is necessary to go below 100 volts and down to 50 and 25 volts. The newer types of incandescent lamps, like the Auer-osmium lamps with their wonderful efficiency, cannot be advantageously manufactured above 35 volts.

Such tensions it is possible to obtain very readily through appropriate transformers, on account of the extraordinary flexibility of the alternating current. In the case of direct current, on account of its rigidly fixed pressure, it is necessary in such cases to have recourse to connecting the lamps in series, thereby losing the most valuable characteristic of incandescent lighting, the independence of the individual lamps.

Again, other types of lamps require higher pressure, such as the Nernst lamp, which at 200 volts gives more satisfactory results than at 100 volts. In the case of alternating current it is possible

to obtain at once this higher pressure even in the case of a 100-volt system, so that each type of lamp can be supplied with the pressure best adapted to it. The latest and apparently most economical type of lamp, the Cooper-Hewitt lamp, has not yet received a practical test on the European continent and even in its native land it must no doubt be further perfected ere it can be considered adapted to general practical use. As far as known here, its adaptability for three-phase currents is the same as for direct current, and in addition it affords a good method of securing an equal loading of the three legs of a polyphase system.

The alternating-current arc lamp was for a long time considered of less value than the direct-current arc lamp. As a matter of fact, with the same consumption of energy at the lamp terminals, the usefully developed light is about 20 per cent greater for direct current than for alternating current. This relation changes at once, however, if account is taken of the fact that about 20 per cent of the energy necessary for a lamp is expended without utilization as a steadying resistance, and this loss can be reduced to a minimum in the case of alternating current by economy coils and inductive resistances. With the alternating current there is secured at the same time the independence of each lamp, while with direct current only two or three lamps can be simultaneously operated on 110 volts and four or five lamps on 220 volts without undue loss.

Enclosed arc lamps of the Jandus type which require higher pressures do not give the light output which is the advantage of the direct-current lamp and they require still greater steadying resistances. The alternating-current arc lamp has lately reached the same value as the direct-current arc lamp, as regards the production of light per unit of energy at the lamp terminals, since chemicals have been added to the carbons, increasing the lighting effect. Thus the alternating current gives better results than the direct current in similar lamps, using economy coils and resistances, as every increasing loss can be obviated. The lighting effect is the same in both lamps and the alternating-current arc lamp has the advantage in construction on account of the inclined carbons, which in these lamps are of the same size and are less likely to cause unequal consumption than the carbons of different diameters in the direct-current lamp. With this construction the inherent defect of alternating-current arc lamps of a lesser lighting of the ground disappears.

Outside of lighting and motors the electric current is used for only a few special purposes, but they are of so little importance, that the special adaptability of a type of current to one of these seldom used applications should not be the deciding factor in the selection of the system.

The production of current is too costly as yet for it to receive wide application for heating purposes. The type of current is indifferent for most heating appliances, but in the case of electric furnaces, where the electrolytic effects might come into play, the direct current is excluded, as also in the case of intense heat from large currents at low tension, in the generation of which special transformers afford the best means.

On the other hand, the direct current meets with better success in soldering with the arc and for large projectors for demonstration. No one would think of supplying a city with direct current on this account, if alternating current were more advantageous in most other respects. For such purposes in isolated cases motor-generator sets can be used, which generate the direct current at once of the desired pressure. This is the case for electrolytic purposes, for which, even with direct current, motor-dynamos are often necessary for conversion in order to avoid too large resistances and the excessive losses due to the reduction of pressure often necessary.

Until we have available lighter storage batteries the electric automobile will have but little hope for a wide application. Charging stations for automobiles, if supplied from an alternating-current distribution, must be equipped with motor-generator sets; but this complication brings with it an advantage, in that the charging pressure can be easily adjusted to the number and state of charge of the cells on charge without additional losses.

On the other hand, there are a large number of special applications which can be enumerated which require in the case of direct-current distribution a conversion into alternating current; for instance, for physicians and dentists who generally require alternating and direct current for instruments which need both kinds of current, for lectures, for watchmakers, for demagnetizing watches, etc.

In these instances, in the case of direct-current networks, small motor-generator sets are required, if all of the desires of the public are to be considered. It is to be noted that direct current is, after all, nothing but commutated alternating current. We have for the conversion, not only motor-generators and rotary converters —

which can also be used in the conversion from direct current to alternating current even though they then give with difficulty the necessary constant periodicity — but in recent times we have the triple connection of the Cooper-Hewitt lamp, converting, however. only small currents, as well as chemical rectifiers with aluminum elements, which, although they give an intermittent direct current, are sufficient for most purposes.

The above observations are doubtless largely of a deductive nature, for if I have compared point by point the direct current with the alternating current in its production and effects, I could give the preference to one or the other system only by the exercise of judgment. It is difficult to compare the several characteristics of the two systems by figures, and finally, after all, it resolves itself into arriving at a conclusion which shows us to which side as a whole the balance trends by making just such specific comparisons.

If it be desired to test the correctness of the problem, it will be necessary to compare the actual operating results obtained from direct-current and alternating-current stations in large cities.

This gives a view not without possibility of objection, for the local conditions are everywhere different, and to reduce them to the same basis is well nigh impossible. In several of the large cities, however, central stations of the different systems are in operation alongside each other under the same outside conditions. A typical example presents itself in Vienna. For the past 15 years there have been in operation three companies, of which one operates an alternating-current station and two others direct-current stations. The smaller direct-current station supplies only a small district, whereas the larger has laid its cables in nearly all streets of the city alongside those of the alternating-current company, so that they cover about the same territory. These two stations we can compare with each other.

The direct-current station uses the five-wire system, 4 x 100 volts, and the other station uses a single and two-phase alternating-current system, which is transformed in house-to-house transformers from 2000 volts to 100 volts.

The following table gives the operating results of the two stations for the past year:

	Austrian values, direct current, 1903	Equivalent U S currency	Austrian values, alternate current, 1902–3.	Equivalent U S currency
Investment...	24 95 mill kr.	$4,990,000	25.16 mill. kr	$5,032,000
Connected load, kw	15,018	15,018 kw	19,033	19,033 kw
Investment per kw	1,660	$332	1 320	$264
Kw-hrs delivered per year	6 6 million	6,600,000	12 0 million	12,000,000
Operating expenses	1.86 million	372,000	2 58 million	516,000
Cost per kw-hr.... . ..	28 h.	5 6¢.	21 5 h	4 3¢
Operating expenses, including 10% for int and dep	4.36 million	$872,000	5 10 million	$1,020,000
Total cost per kw-hr.	66 h.	13 2¢	42 5 h.	8.5¢

These figures demonstrate both parts of my contention: First, the consumer recognizes no advantage as regards direct current; otherwise, as the rates of both companies are the same, the connected load of the alternating-current station would be less. Second, the producer is able to produce a unit of alternating current cheaper than a unit of direct current. Vienna furnishes the proof also of several other assertions which I have maintained. Another station has been added recently, which was erected by the municipality. In this splendidly planned station three-phase currents are generated at 5000 volts, converted into 2 x 200 volts in sub-stations equipped with motor generators and storage batteries. The result has been that in the important business districts where the competition is most keen, the new station has found it necessary, in order to meet the competition, to install an extensive alternating-current secondary network with an interconnected low-tension network of 100 volts in addition to the secondary direct-current cables.

Of the 17 European cities in the German statistics which have over 200,000 inhabitants, there were still 10 in the year 1894 which had exclusively direct-current service. Of these 10 direct-current stations, up to this date 8 have already gone over to the partial use of alternating current — as a rule, it is true, only for operating direct-current motor generators — so that only two direct-current stations are confining themselves to the direct current. In no case has any of the above cities changed over from alternating current to direct current.

In all of the above considerations I have always spoken of alternating current in general without comparing with the direct current any particular alternating-current system. With the large differences in operation and construction between the several kinds of

alternating current, there is certainly in some cases one kind and in other cases another kind to be preferred, and it is not easy to find a system which combines in itself all of the advantages of the alternating current and avoids its disadvantages.

Notwithstanding this, it is necessary to decide on one of these systems. In proposing a new plant for a large city I would proceed about as follows, and the reasons are to be found in the requirements of a good current distribution previously outlined: At each of two points located about diametrically opposite in the periphery of the city — I assume about 12 km (7.5 miles) distance — there would be located on cheap ground, with convenient access for coal and water, a large central station, each station containing six to eight large generating units.

The dynamos would be built on a principle somewhat similar to the monocyclic system, so that with a heavy single-phase winding there would be combined a correspondingly weaker auxiliary winding in quadrature, with and connected to the middle point of the

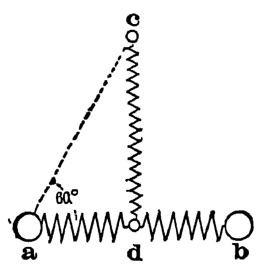


FIG. 2.

main winding, thereby giving exactly three-phase alternating current. (Fig. 2.) The number of periods would be 50 cycles per second, and the voltage about 3000 volts, so that a single transformation could safely be made to 100 volts. The cables would have three strands, to consist of two heavy and one lighter strand, under a common metallic sheath. At the points of heavier load, particularly for large power demands, single transformers would be installed; for districts in which the demand is more distributed, transformer sub-stations would be used, from which would go out secondary circuits of a similar construction to the primary circuits. In the suburbs and where there was only a small load, a four-conductor cable for 2 × 100 volts, with a smaller neutral conductor (Fig. 2, d), might be used. The transformers would normally be

single-phase, and three-phase transformers would only be connected in case of power load, one phase to be connected in parallel with the former. The transformers could be cut in and out by automatic primary switches, particularly in cases where a single transformer would not carry the load. In the larger transformer sub-stations the switching would be done by hand before and after the maximum load. The lighting load would be supplied from the main winding of the dynamo through the single-phase transformers, at a pressure of 100 or 2×100 volts, and the auxiliary winding need only have capacity enough to supply the power load. Only the lighting phase would be regulated; the motors would not be affected by the small departures from the normal phase shifting and the variations in the pressure which might result in the auxiliary winding. The primary cables of both stations should meet at as many points of the city as possible, avoiding the laying of both sets of cables in the same trench, particularly in the center of traffic, where theaters and important installations require special security of current supply. In case the current in one of the circuits should fail for any cause, the second station could be called up for the supply.

It would be expected that in such a system the use of the auxiliary winding for operating the three-phase motors would grow less and less. The progress made in the construction of single-phase motors is so great that the above plan is no doubt the most practicable at this time, but in a few years it will surely be superseded by the pure single-phase system with its simplicity of construction and operation, to which then it can be changed over without any change in the dynamos or cable network.

The tremendous development of alternating-current technology has thus resulted in an important change in the fundamental principles for the distribution of current in large cities. If during the infancy of our profession many electrical engineers held fast to the direct current because its laws were more familiar to them, and because its operations appealed to them on account of their having occupied themselves with galvanic batteries, they have become converted, however, in the course of time to the view that the alternating current represents a step forward, and that they were in the right who would not give up their enduring faith in the ultimate victory of the alternating-current system.

DISCUSSION.

CHAIRMAN LIEB: We now have the three papers open for general discussion.

Mr. TOWNSEND WOLCOTT: From the earliest days in the use of alternating current, we have been told that one of the great advantages in the use of that current was that it dispensed with the commutator. Dr. Stern emphasizes that point, and goes on to say how much better the alternating current is, because it is unnecessary to use any commutator, even on a polyphase motor. Then he ends by saying that the latest development of all, showing its supreme advantages, is to use the commutator motor for alternating current. One other point, to which he refers, is the much-talked-of electrolysis of the direct current on the insulation of the cables. I must plead ignorance on that point. I have been trying to find how much current goes through the cable. All the rubber insulation that I examined had from 500 to 1000 megohms to the mile. Now, at 1000 volts, with an insulation of 1000 megohms-miles, it would take 1,000,000 hours to get an ampere-hour through an insulation of the cable. One million hours is more than one hundred years. I think, therefore, that the electrolysis due to leakage through the insulation would not have a great effect.

Col. R. E. B. CROMPTON: I think we ought to thank our Chairman for having obtained from Mr. Stern such an interesting paper but which I venture to think is so much out of date, or rather out of touch with modern practice, that it is hardly suitable for discussion to-day. Personally, there is hardly a statement in the paper with which I agree, unless it is where he states on page 12, paragraph 2, that the polyphase motor is easier to manufacture and to maintain than the direct-current one. As a manufacturer I agree with him in this. I also agree with him in his advocacy of the frequency of fifty cycles per second. Turning to the other papers I wish first to say that I have come with other English engineers to study your methods of electrical supply so that by interchanging of ideas we may learn from one another. In England we appear to have arrived at conclusions which differ widely from yours, and the two papers read to-day point this out. The problem of light and power supply which was put before English engineers differs materially from your problem. With us the gas competition has from the commencement been far fiercer than with you; moreover you have found it easier to obtain an income from motors than we have, probably from differences in the arrangement of the manufacturing and residential quarters of the cities in our respective countries. However, the slow progress in England in obtaining a motor load is gradually correcting itself, principally on account of the lower prices at which small motors are now sold. At any rate the comparatively small motor load in England as compared with America has greatly differentiated the two countries, and has made the average load factor in England notably lower than the load factor in America. In England our variety of distribution systems is not so great as we find here. We started with three-wire 200 or 220-volt systems, distributing at 110 volts. We have everywhere practically doubled this voltage. All

our largest cities in England, including London with its 6,000,000 inhabitants, after very careful consideration practically adopted what you have called the double voltage system. This doubling the voltage was not adopted without a struggle. For a long time the lamp manufacturers opposed us, and told the consumers, probably with some reason, that they would be at a disadvantage, as lamps of the double voltage could not be made so efficient as lamps at the single voltage, but we showed that this could be remedied by refinements in lamp manufacture, so that now it would be very difficult for the consumer to find that he was at any practical disadvantage on account of inferior efficiency of the double-voltage lamps. The result is that the majority of our consumers take their supply at pressures varying from 200 volts in London up to 250 volts in Glasgow. We therefore consider this question settled and therefore completely disagree with all the arguments on this point in both Mr. Torchio's and Mr. Dow's paper. It follows that instead of the economy of the double-voltage system being at the bottom of the list as shown in Table 1, page 599, of Mr. Torchio's paper, we feel that the system should be placed at the top. The most economically worked systems are practically those shown on system No. 17, *i. e.*, a 500-volt three-wire distribution for light and power from sub-stations provided with rotary converters, but it is fair to say that we have not yet developed this to its fullest economical efficiency as we have up to the present only used motor generators and not rotary converters. As we are substituting rotary converters we expect to obtain increased efficiency. Mr. Torchio has attempted to deal with this matter in a very fascinating way, a way which I tried myself some years ago, but which I have finally abandoned as a waste of time, that is to make a study of an ideal town, and lay it out and base arguments upon it. I prepared my calculations for an ideal town at great labor and cost to myself, but I never found that any such ideal town exists to which my calculations can be usefully applied. Take by way of illustration this town of St. Louis — I hope I do not hurt any resident's feelings by saying that it is not "ideal" in its temperature — it would be very advisable to supply it with means of cooling by agitating the air by fans such as we provide in Calcutta. I am engineer-in-chief of the Calcutta Company, and 80 per cent of our load is obtained by running continuously large-sized overhead fans, which have made such a difference in the climate of Calcutta, that I venture to assert that if they were used to an equal extent in St. Louis it would, at all events at this time of the year, be a much more habitable place than it is. I hope the inhabitants of St. Louis will see that I speak as a large manufacturer of these fans. I mention Calcutta as a convenient means of showing you how ideal conditions are so profoundly modified by the special requirements of a town. For in Calcutta the fans are used both in the business quarter in the offices, and in the homes of the residents, which are at a considerable distance from the business quarter. The hours of business are from 9 in the morning till 6 in the evening, but the consumer wants the fans to run throughout the night in his home, so that nearly the whole of the fan load generated at one station is transferred from the business quarter of the town to the residential quarter; so that as regards this fan load, although the load factor of the generating station

is extremely good, that of the feeders and distributing system supplying both quarters is only half so good. I find that every town for which I have made a study of the electric supply has special requirements of this kind, which so profoundly modify the distribution calculations as to render ideal calculations practically useless. Every town has its own grouping of the population into power users and light users. There also comes in this climatic condition and the use of power for fans and probably there will be large demands in future for producing artificial cold by compressing and then expanding air. I look forward to this artificial production of cold as a very important future for our power supply. As so many of our members wish to speak on this point, I have no time to controvert many of the statements in both papers which refer to English practice, for instance as regards the question of lamp testing, although we admit that our system is not as complete as Mr. Dow has stated in the case of the Edison Companies. We are unable to introduce such a system, as we are not allowed to do so by law. Our customers are free to buy the lamps wherever they desire and although I admit the question has some importance, it is considered that it has gone into secondary rank. I think I am correct in saying that the change I have referred to in England of doubling the voltage has had the effect of steadily diminishing the cost of the kilowatt-hour, or as we call it "The Board of Trade Unit." This change has greatly reduced the cost of our distribution systems, and the capital and maintenance charges belonging to them. On another matter, I must point out that in England we, the engineers of supply companies, are greatly indebted to Mr. Hammond, who is in the room to-day, for the splendid work he initiated thirteen years ago, and has carried out steadily ever since, of analysing the annual accounts of all the large supply companies in England. These are published weekly in a paper called the "Electrical Times." At any rate Mr. Hammond can speak with much greater authority on the question of these costs than I can do, but I think I am correct in saying that at any rate Mr. Hammond's statistics show that the arguments raised in favor of the superiority and cheapness of the alternating-current supply are not supported by fact. I can put it even stronger than this. I think nobody in England considers that the advantages attributed to the alternating current are sufficient to outweigh the undoubted advantages which direct current gives us in enabling us to use storage batteries. I am a staunch supporter of the storage-battery system. As chairman of one of the largest London supply companies, which has from the very commencement produced record cost figures, I attribute our low costs greatly to the fact that we are the largest users of electrical storage. The day when the uncertain cost of the unkeep of storage batteries was a powerful argument against their use has gone by. We used to put aside annual sums of about 14 per cent per annum on the cost of our accumulator plant, in order to make certain that we should maintain it in good condition, but nowadays we find we can contract to have it maintained at 6 per cent, by substantial companies who can give guarantees that their maintenance contracts will be fulfilled for a long period of years. In a recent case where two companies agreed to construct a joint generating station for increase of their generating plant a stringent agreement was

lrawn up to ensure that the usage of this supply by the two companies should be fair and reasonable, but it was found that whereas company 'A" owing to its large storage capacity was able to take its supply from the joint generating station at a high load factor and whereas the other company "B" owing to insufficient storage took it at a bad load factor, t was easily proved that the company "B" was violating the spirit of the agreement and they have agreed to amend their ways by increasing their storage by practically doubling it, company "B" admitting that if the matter had gone into court they would not have had any case.

Mr. Robert Hammond: I hesitate very much in following Col. Crompton, because I have considered that on these occasions the nationality of the speakers should be alternated somewhat in the discussion; but as I have an engagement, I will venture to speak instead of waiting for an American gentleman to continue the debate. The watch is before you, Mr. Chairman, and I do not want to trespass on your patience long; but would wish, as we had no opportunity of doing so yesterday, time being so limited, to express thê great satisfaction we feel in being members of this section, under its talented chairman who, in addition to his other abilities, is translating into the vulgar tongue all the papers he gets from every part of the world, including this one of Dr. Stern. I ventured to say yesterday, that one had to consider in the question of the cost of production the actual ultimate cost, in which was included not only the operating cost, but the 10 per cent, which seems necessary to be paid upon capital expenditure. I am entirely with Col. Crompton in this matter. We have come to America to learn, and ever since we put our foot on American soil, we have been going on until this paper of Mr. Dow first struck us last night when we came home from the Exposition; and we saw we had our chance to teach the great American nation something, at least we thought we had. Col. Crompton has made a kindly reference to the analytical work which for the past fifteen years have carried on. We have the very great advantage in England of holding powers under Government which makes it a condition that the actual cost of operations of the concerns under certain headings, prescribed by them, must be duly filled out at the Board of Trade, which reports must be handed out to any one interested in them, or rather copies of the reports, upon the presentation of a quarter, or, as we call it, a shilling. With the necessary number of shillings I have gone and I have demanded the accounts of every single electrical concern in the country. Would that I could pay a shilling to Mr. Lieb and make him disclose to me what is the cost, in the Edison Company of New York, of delivering every kind of current to every kind of consumer. The latest accounts that I have analyzed are those of a concern, an undertaking which I think illustrates the advantage of keeping an exact account of the cost of mains separate from the remaining capital expenditure. We do seriously think that the companies throughout the length and breadth of the United States will have to tackle this question of doubling their voltage. We grasped the problem which lay before us in England by supplying so many milliion lamps — giving them away — and we had to face it, because we felt that if we did not face it, we should have to put

in so much capital in extra distributing mains, and the interest and depreciation on this would far outweigh any small difference in efficiency. We read in these papers of loss of current. Mr. Lieb could figure it out to see what the 10 per cent amounted to. Take a system with which I am connected in London, we started with a clean field — in the past we have not had the opportunities of starting with clean fields but we have generally started with a little system and gradually built it up to a bigger system. But when you start with a clean sheet what do you do? You go on in a bold manner; you do not begin in a peddling way, and the result was that in Hackney we spent $600,000 in the generating plant — everything outside of the distributing system — and $600,000 in the distributing system. Had I not been using straightaway the 480 volts pressure, I should have had to recommend these gentlemen, much against my desire, to spend instead $2,400,000 in the mains, but by the application of 480 volts, and the supplying of lamps at 240 volts, I was able to keep down the distributing system over a large area to the sum of $600,000. The result of the first year's work was, the supply of electricity starting at zero and running up to a matter of 60,000 8-cp lamps at the end of the year, that we were delivering to the consumers at an all around cost, excluding the interest upon the capital, but an all around operating cost of generation and distribution, of two cents (1.03 pence) per kw-hour. We can see, by having these costs to compare with one place and the other, that this use of the higher voltage plant is not the wasteful use that some would make it. I am not one of those who consider that this paper on the alternating current for large cities is so bad a paper. I had the pleasure of visiting Vienna and making the acquaintance of Dr. Stern, and I feel that in the future these alternating-current systems will take a very much higher place than the great champions of the direct-current system, including Col. Crompton, would give it. I had occasion recently in the city of Dublin to advise them as to what they should do in order to put their systems on a sound basis. I advised alternating current. I did not see Mr. Lieb, unfortunately, but I also went through the principal cities of Europe, and the final result was that I recommended them to put down a three-phase system, because we had water and coal close by (some four miles from the city), and therefore I had to have an alternating system; but having got my three-phase system into the center of the city, I think I would not change it into anything else. I bring up the two or three thousand kilowatts to a central switchboard in the center of the city and distribute it to some twenty sub-stations situated in various parts of the city. In these sub-stations it is transformed down to 200 volts for lighting and 346 volts for power. I have four wires in Dublin, and therefore, between the neutral and any leg of the circuit, there are 200 volts for lighting, and on the three-phases 346 volts for power purposes. So far the system has worked excellently. It does seem to me that the simpler you can make the systems the better. Mr. Torchio gives a menu of eighteen systems; well, I am rather inclined to limit it to two — either have the alternating-current system throughout, or the direct-current system throughout. You cannot have the direct-current system clean throughout,

in a district which reaches two and one-half miles from the central station, except by duplicating the stations or bringing in the alternating current to help out. In Hackney, we have a district extending two and one-half miles from the station, but by the use of the double voltage we keep the district supplied. When the distance exceeds two and one-half miles, and goes to four miles and over, I believe we should use alternating current; and in spite of the features in Mr. Stern's paper about demagnetizing watches with alternating current and similar things, I believe on the whole he has the right end of the stick.

Mr. LOUIS A. FERGUSON: After what Col. Crompton has said about Dr. Stern's paper, I suppose we ought not to discuss it; but really it seems to me he has taken what we have always considered to be the disadvantages of the alternating-current system and converted them into advantages. He makes claims which it seems to me — I hardly like to use the word — are absurd for the alternating-current system. He admits that one of the very important applications of electricity in large cities is for elevator purposes, and goes on to say that the alternating-current motor is the most advantageous for that purpose. We all know in America — from our experience in the large cities at least — that the alternating current is not at all applicable for first-class elevator service. For anything above a speed of 250 feet per minute, the alternating-current elevator is impossible. We have this condition to meet in New York, Brooklyn, Philadelphia and Chicago, of supplying current to buildings fourteen, sixteen and twenty stories high. The only way we can handle the business is with direct-current elevators. The elevator situation, as Dr. Stern attempted to point out, is an extremely important one. We are unable to take out isolated plants in these large cities unless we can supply the elevator service, and in order to do that, we must have an elevator which will give satisfaction, and therefore it seems to me that the use of direct current for this purpose is an extremely important one. As Mr. Hammond says, we need not consider the matter of demagnetizing of watches and such minor matters. I cannot agree with Mr. Hammond that we should do one thing or the other — use either alternating currents, only, or direct currents only. I am an advocate rather of a combination of the two, to use alternating currents for transmission and direct currents for distribution; thereby obtaining all the advantages of alternating currents, and all the advantages of direct currents without the disadvantages of either.

Mr. ARTHUR WILLIAMS: I think Dr. Stern's paper will answer a useful purpose at this time, in that it has set forth nearly all the advantages of the alternating-current system, all the claims which can be put forward in favor of that system; and after these advantages have been carefully considered, he shows how much further the advance has been led in the direct-current system of distribution, which may be called the ideal system for distribution of current. Dr. Stern draws comparisons between his Vienna system with direct currents and other systems which surround him in Vienna. I think the picture would not be complete without a description of Dr. Stern and a comparative description of his opponents. Having accompanied the chairman of this section on an

European trip, I had the pleasure of meeting Dr. Stern, and I retain a picture of a very cultivated man of strong personality.

I have a great hesitation in criticising the practice of any of the companies represented by our foreign visitors; and yet I think it is true that no American has ever returned from a visit to the European cities without feeling in a measure disappointed at the lighting standards which he found adopted. We heard them describe what we think is a lamp of high standard in candle-power and brilliancy, and the difference in the lamps, due to the fact that the companies leave it to the customers to purchase lamps wherever they like. I think the consumer buys incandescent lamps the same as he buys crockery. We had to consider that problem here; many of our large customers proposed to buy their own lamps. A few years ago I was discussing lamp efficiencies with a man who was operating a large private plant. I expected, by substituting the lamps which we would sell him, for the lamps which he was purchasing, that we would make a large saving in the use of current. When we discussed the matter, he took me to a workshop, and among the appliances which he had was the photometer. For many years he had been measuring the efficiency and candle-power of the lamps bought in the open market. I think we should hesitate to accept the principle that our small consumers should be permitted to purchase their own incandescent lamps.

We look upon the light as the unit sold, and not the kilowatt-hour. Practically we sell light. That is what we are judged by, and what our system is judged by. I think it would be unwise in our American practice to put ourselves in the position of having only the cost of current considered without regard to the cost of light to our customer. The difference between the 120-volt lamps and 200-volt lamps, in a commercial sense, ranges from 10 to 25 per cent.

Mr. Hammond speaks of 60,000 8-cp lamps. In the past few days we have made contracts for 30,000 8-cp lamps, for the equipment of a single building in New York city.

In regard to Mr. Hammond's contribution to the storage battery, I would like to say that it appears to me that, bearing on our discussion on rates yesterday, with a large increase in storage battery we may reach a point where we can compare our storage capacities with the storage capacities of the gas companies and thereby reach a level with the gas rates.

Chairman Lieb — Will any gentleman from the Continent, France or Italy, take the floor and give us his views on this important matter? If not, I will call on the gentlemen in succession to close the discussion. I consider that Mr. Williams's remarks have covered Mr. Dow's paper, as well as Dr. Stern's paper, and I will give the floor to Mr. Torchio for as brief closing remarks as possible, as we wish to take up one other paper before adjournment.

Mr. Torchio: In presenting this paper, I did not intend to open a discussion on the merits of the direct-current and alternating-current systems. I considered the question settled, at least in this country. The large cities in this country, like New York, Chicago and Boston, have direct-current low-tension 110- or 120-volt lamps and they will not change.

They could not afford to change in the future. The question is settled as far as these cities are concerned. What I did intend to bring forward in my paper was the condition that exists, perhaps, more in this country than in any other, in the medium-sized cities where they still operate overhead lines for alternating-current distribution for lighting, and 500-volt direct-current distribution for power. In many of these cities the system has grown to large proportions, and the density of traffic makes imperative the burying of the wires. As to how to do it I did not commit myself, in my conclusions, either to the direct current or to the alternating current; as a matter of fact, I left the question open to suit conditions. The conditions represented in the paper are not ideal, as the American engineers will recognize them to be characteristic of many American cities. Of course, in this country, everything is classified to a greater degree than is the case on the Continent, and we have developed in our cities a business section for purely business purposes, quite independent and separate from the residential sections. In this section, the wheels of commence are moving faster every day and the use of power for various purposes is increasing rapidly. The supply of light and power to this section represents a great percentage of the company's total business of the city, and it is for these conditions that I had it in mind to open the discussion.

Unfortunately, the discussion did not take the trend I intended, but I hope that the paper will be of some use, especially to the American engineers, in assisting them in the solution of their problems. Col. Crompton laid stress on the double-voltage lamp. He says that several years ago, they forced the lamp manufacturers on the other side to make the double-voltage lamp as good as the low-voltage lamp. This statement should be qualified. I believe that Col. Crompton meant that in England they forced the manufacturers to make double-voltage lamps as good as 3.6 to 3.8 watts-per-candle efficiency lamps could be made, because five years ago I know that lamps on the English circuits varied from 4 to 5, 6 and 7 watts per candle, and the 3.6–3.8 watts per candle lamp were a real boon to the industry. But it is an absolute impossibility, in my opinion, to manufacture a double-voltage lamp that will operate at 3.1 watts per candle, and furthermore, leave to the customer the freedom of purchasing the lamps anywhere from any manufacturer they desire. To obtain good results from high efficiency lamps, they must be operated very close to the rated voltage. Now, makers of incandescent lamps recognize the fact that individual close voltage requirements for their product can only be met commercially by careful assortment of all lamps and liberal diversification of voltage required by the trade. This involves the control of the lamp supply in different localities. In America, it has been found that this can only be accomplished by free supply of lamps to the customers by the operating companies. By making different cities adopt different standard operating voltages, the manufacturers are enabled to supply each company with lamps very closely rated as suited to the respective voltage requirements. Thus St. Louis may use 104-volt lamps, Chicago, 115-volt lamps, New York, 120-volt lamps, etc.

I want to say one word in reference to Mr. Hammond's figures in re-

gard to the copper saving he made for the plant where he was able to use the double-voltage lamps with an expenditure of $600,000, while an expenditure of $2,400,000 would have been required if he had used low-voltage lamps. It is a fact, not well recognized, that with a 500-volt distribution, you require the same amount of copper for feeders as with a 250-volt distribution, because if you figure out the problem you will find that you will cover, with 500-volt distribution, four times as much territory from each sub-station, as with the 250-volt distribution. The saving will be in sub-station, real estate and building investment and operating cost, but the saving in copper is only confined to the mains. Now, the saving in the mains is not in proportion to the voltage. The cost of the cable main is the result of the cost of the copper, plus certain other factors, like insulation and lead cover, which do not increase in proportion to the cross-section. Therefore, you may be able to use with low-voltage lamps a larger main than you would use with double-voltage lamps, and still not double or quadruple the cost, as Mr. Hammond says, because you can double the cross-section of the main, with an increased cost of cable of perhaps only 60 or 70 per cent.

Mr. Alex. Dow (communicated): That Dr. Gotthold Stern believes in superiority of an alternating-current supply and that he has attained good commercial results with such a distribution seems to be demonstrated by his paper. The paper does not demonstrate, however, that the selection of alternating current rather than direct current is the reason why good results have been obtained. Dr. Stern claims for the alternating current some advantages which do not belong to it *per se* but are incidental to his manner of applying it. He claims for it other advantages which I cannot admit it to possess either directly or incidentally.

For instance, on page 647, Dr. Stern discusses the 200-volt incandescent lamp in comparison with the 100-volt incandescent lamp on the assumption that the former is a direct-current and the other an alternating-current lamp. This is an unwarranted assumption. In the United States we have not found it necessary in our distributions in large cities to use the 200-volt lamp, and we think that the wide adoption of the 200-volt lamp by European central stations is in many cases based upon insufficient premises and in other cases is warranted only by reasons which are purely local.

On page 648 Dr. Stern discusses arc lamps and claims for the alternating current the advantages resulting from the use of chemically treated carbons. In this also he claims too much. In direct-current practice we have in the magnetite arc entirely eliminated the upper carbon and substituted for the lower carbon a stick of magnetic oxide, with the result of better light and less cost than is so far practicable with any alternating-current device. When we shall abandon electrodes of pure carbon, which in general practice we have not yet done, it will be found that the direct-current arc profits as much by the new methods as does the alternating arc.

On page 637 Dr. Stern seems to claim as a merit of alternating-current distribution the fact that storage batteries practically cannot be used with it. I do not think he should claim a limitation as an advantage. His contention that the real purpose of a battery should be to integrate the

daily load curve is not acceptable to-day to any user of batteries. The function of the battery is to eliminate minor variations of the load curve, and above all other things to serve as an instantaneous reserve source of current. Dr. Stern's denunciation of the battery reads somewhat like the declaration by the fox in the fable — that the grapes beyond his reach were surely sour.

The contentions on page 640, 641 and 642 as to the less troubles found in alternating cables are not borne out by practice. Indeed, I cannot take seriously Dr. Stern's claim as an advantage of the alternating current the absence of electrolytic action in the cables. Neither he nor I nor any other engineer would tolerate any cable construction within which electrolytic action might be initiated. Theoretically a method or material of insulation which with direct current might be subject to electrolysis could be used with alternating current, but no central station engineer would for a moment consider such a method. If theories are to be discussed we might as well require that alternating-current cables should be insulated against the maximum e.m.f. while only requiring that direct-current cables should be insulated against the mean e.m.f. Practically, any cable which is acceptable for the same effective voltage is good for either direct or alternating supply.

While talking of cables I desire to say that American manufacturers of underground cables have for at least ten years past sold their product guaranteed for use on direct-current series circuits of 5000 to 7000 volts — this with reference to Dr. Stern's statement at the end of the third paragraph on page 641.

At the foot of page 642 and again on page 643 Dr. Stern discusses the use of transformers as against rotary converters. His view of this subject is broad and in general correct. In my paper on "The Continuous-Current Distributing Systems of American Cities" I have indicated similar general conclusions. But I have to challenge his statement that automatic switching apparatus for transformers can be applied to scattered transformers. Such devices have been sought for years and have been invented many times, but not one of these devices has come into general use. The fact of it is — and I think Dr. Stern knows it — that no central station engineer wishes to be responsible for the operation of these devices.

In writing the third paragraph on page 643, Dr. Stern seems to have overlooked the general rule which dictates the establishment of a new sub-station as soon as the saving by shortening of secondary mains will equal the cost of the building and switching apparatus. The lowest total investment is obtained by an application of this rule. And throughout the entire paper he seems to have overlooked the well-known fact when converting or transforming apparatus is concentrated in a few sub-stations, the amount of apparatus required will approximate closely to the maximum demand of the system, whereas when it is scattered in many sub-stations or when (like house-to-house transformers) it is distributed on customers' premises, the apparatus required will approximate to the connected load. Connected load and maximum demand have very different values in any urban system. If a district largely residential be served by house-

to-house transformers, according to Dr. Stern's own figures on page 643 the transformers will be equal to 80 per cent of the connected load. The same district if served from a single sub-station will only require transformers equal to 25 per cent of the connected load. A district where the chief demand is from factory motors will, if house-to-house transformers are used, require at least 75 per cent of the connected load; while transformers in a single sub-station need not equal 50 per cent of the connected load. These considerations will seriously affect any specific comparison between direct and alternating distribution, and they must be given some value in a general comparison. Tney tend under American conditions to the establishment of more sub-stations than are ordinarily provided, but to a much less number of sub-stations than contemplated by Dr. Stern's proposal.

Of local circumstances instanced by Dr. Stern as proofs of his conclusions, the following are most prominent: He claims on page 645 that the polyphase motor has surpassed the direct-current motor in elevator service. It may be so in Europe. Since Dr. Stern says so, it doubtless is so. My comment is that either the European builders of polyphase elevator motors have concealed from us some excellent work, or the European builders of direct-current elevator motors are habitually doing what we in America would call very bad work. I would like to know which conclusion is the correct one.

Further, on page 644 Dr. Stern says that according to the statistics of most of the large European cities the average use of current for motors is not greater than current for lighting. On page 644 he figures the average use of all connected services at 400 hours per annum. We find that the use of factory motors in terms of the connected load is between 1000 and 1500 hours per annum. Even the despised elevator motor, while its use in terms of connected load is very small, makes a magnificent showing when enough elevators are connected to the system so that the sum of their operation gives a practically steady load. To put it otherwise, an individual elevator is not a desirable customer but 100 elevators distributed throughout the area make a very desirable addition to our business. In respect of the use of elevators, European conditions undoubtedly differ from ours, but in respect of the use of factory motors they surely cannot differ materially.

Dr. Stern's comparison of two Vienna central stations connot be discussed as it deserves without more information than he gives. I observe, however, that Dr. Stern does not claim that the conditions governing these two stations are identical excepting as to the use of direct current and alternating current respectively. I think that there must be other and much more important differences. The difference in machinery would not account for the difference between $332 and $264 of investment per kw. Neither should the difference in current account for the difference in operating expenses between 5.6 cents and 4.3 cents. This latter difference is sufficiently accounted for by the fact that the direct-current station has an annual output of 439 kw-hours per kw connected, while the alternating-current station has an annual output of 636 kw-hours per kw connected. As a central station manager I cannot accept this comparison

of costs as a demonstration of alternating-current superiority. As an American I cannot overlook the fact that all similar comparisons in the United States have resulted in favor of direct current.

To conclude my remarks, I desire to say that no one can appreciate more than I do the magnificent work that has been done by alternating-current engineers, and that (as I have shown in my paper read before this section) no one is better aware than I am that the American preference for direct-current distribution has its basis in the past superiority of that system rather than to its present superiority. To me it seems that the practical and commercial differences between the two systems are from year to year disappearing, and I, like other American central station managers, am very slow to extend my direct-current area to the displacement of alternating-current service. The advent of a satisfactory and cheap single-phase motor is what the alternating-current system most needs. With such a motor and with the intelligent application of sub-station distribution, it will be possible to serve properly an urban area by means of alternating currents. In the meantime American conditions require direct-current distribution, and the central station manager who ties himself to alternating currents has to say that "the grapes are sour" not only with regard to storage batteries, but with regard to much desirable business which a direct-current distribution would enable him to reach.

CHAIRMAN LIEB — We have still one paper before us, and while it is of a character which will require considerable study and analysis, we do not wish to handicap it in its presentation on account of the lateness of the hour. However, I think we can give it sufficient consideration in the time left at our disposal. I will ask Mr. Louis A. Ferguson, delegate of the Association of Edison Illuminating Companies, to present his paper on "Underground Electrical Construction." During the presentation of this paper, I will ask Mr. W. C. L. Eglin, another delegate of the Association of Edison Illuminating Companies, to preside over the section.

(CHAIRMAN EGLIN presiding.)

MR. FERGUSON presented his paper.

UNDERGROUND ELECTRICAL CONSTRUCTION.

BY LOUIS A. FERGUSON, *Delegate Association of Edison Illuminating Companies.*

It is generally conceded that where the business will warrant the investment, electrical lines are much better under ground than overhead. The cost of underground work is several times that of overhead, and it is only in districts of fairly dense load, and in the case of important transmission lines, that the expense of underground lines is justified. In almost all cities of 50,000 inhabitants or over, there is a business section and possibly in addition a small portion of the residence section, where it will be found desirable to install underground lines. Local conditions will govern each case, and it is hardly possible to lay down general rules in regard to the comparative desirability of overhead and underground lines.

Electric companies in the United States are practically committed to the drawing-in system of cables and conduit, and it is to such a system that this paper refers particularly. What is commonly known as the "Edison Tube System" has been used in the past extensively for low-tension work, and is still used to a limited extent, but on account of the relatively short life of the tube and the higher cost of repairs, its use in late years has greatly diminished.

CONDUIT.

Various forms of ducts are on the market for underground work, vitrified clay tile being used much more than all other kinds of conduit. There seems to be no good reason for using pump-log or ducts made of any inflammable material, particularly for electric light or power work. Cement-lined iron pipe has been used to a certain extent, but there has been some trouble with cables in these pipes, due to the lead on the cables being in contact with the iron ferrule at the ends of the lengths of pipe. Cement pipe is also used to a limited extent. Vitrified clay pipe is furnished in both single and multiple construction. Multiple conduit pipe usually has square holes and single-duct either square or round holes. Conduit with square holes is preferable on account of the greater

ease with which cables may be drawn in, and also on account of the large number of cables which may be installed in one duct. In general it is undesirable to pull several cables in one duct, but in cases of small cables it is necessary to do so to avoid wasting duct space.

Multiple-duct is furnished in sizes ranging from two to nine ducts, and in lengths ranging up to six feet, although the six-feet lengths are not made to any great extent, on account of the danger of warping. Three feet is the standard size for four- and six-duct multiples. Nine-duct tile is difficult to handle, and four- and six-duct sections are most generally used. There are two objections to the use of multiple-duct as compared with single-duct. First, between any two cables in one piece of multiple-duct there is only one wall, and second, it is not possible to break joints as with single-duct conduit. These two things increase the liability of a fire in one duct reaching cables in adjoining ducts. In single-duct construction there are always two walls between adjacent cables and all joints are broken, so that there is a very slight possibility of a burn-out in one cable reaching any adjoining cable. Single-duct construction is unquestionably the best, particularly for large companies, where a burn-out on a cable is liable to be severe on account of the large amount of power concentrated at that point.

The first cost of single and multiple tile is approximately the same. The cost of installing multiple-duct should be approximately 15 per cent less per duct foot than for single-duct. The weight of single-duct tile is about 20 per cent more per duct foot than for four- and six-duct multiples. The lower cost of installing multiple-duct is due to the lower freight charges, on account of the lesser weight, and also to the smaller cost for labor. It is usually necessary to employ a bricklayer for installing single-duct conduit, and multiple-duct may generally be installed with the better class of laborers.

Conduit should always be bought according to specifications and if a large amount is to be purchased it will pay to detail an inspector at the factory, to make sure that nothing but good tile is loaded. There is always a certain amount of bad tile in every kiln, and your own inspector will naturally be more careful in sorting this than the manufacturer. Your inspector can also keep you advised as to shipments and the general state of work at the factory. On large conduit installations it is frequently difficult to arrange shipments so that the tile is delivered as needed, and it is

hard to avoid the two extremes of paying demurrage on loaded cars or of being out of tile altogether.

The general dimensions of the ordinary forms of clay conduit are given in the diagrams in Fig. 1.

It should be borne in mind that a conduit line of a large number of ducts is to be avoided wherever possible. While a large line may be permissible for telephone work, it certainly is not desirable for electric light or power work. The entire output of a station or sub-station of any considerable size should not be carried out through one conduit line, but should be divided between two

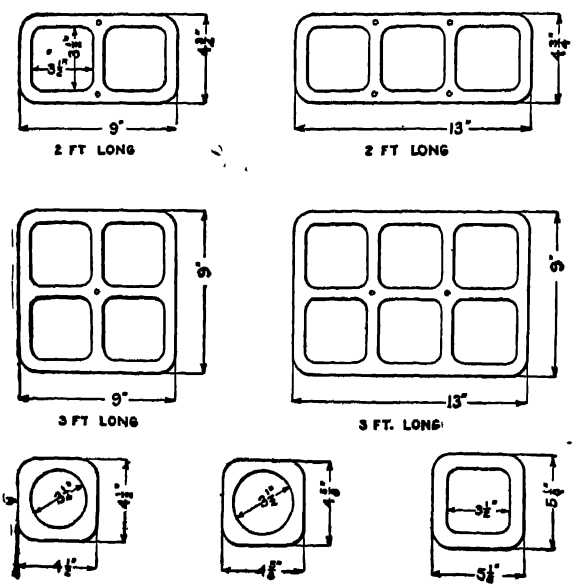


FIG. 1. MULTIPLE-AND SINGLE-TILE DUCTS.

or more lines running on different streets. The objections to a large conduit line are several. If a large amount of current is being carried, the heat given off from the cables is not easily radiated and the resistance of all lines is materially increased; also a bad manhole fire may burn out all the cables in one manhole, although this should not happen if the cables are properly trained and fireproofed. A conduit line is occasionally injured by the caving in of the street, due to building operations, or to broken water pipe. It is not possible to satisfactorily support and protect a large number of cables in one manhole. It is also difficult

to make a safe installation of cables in a large station where all of the cables leave the station by one conduit line.

A good arrangement of ducts is secured by laying them not more than four wide and as high as necessary to obtain the required number of ducts. These ducts should be separated into two vertical rows where they enter the manhole, the separation being about eight inches. The separating of the ducts should begin about five or six feet back from the manhole. This arrangement gives two vertical rows of cables on each side of the manhole and leaves them much easier to support and protect than would be the case with three or more vertical rows. With an arrangement of ducts not more than four wide no cable can have more than one other duct between it and the surrounding earth, thus permitting good radiation of heat.

The detail construction of conduit lines is so fully covered in the paper on "Underground Construction" presented to the National Electric Light Association by Mr. W. P. Hancock at the meeting held in Boston in May of this year that it is considered unnecessary to further discuss it in this paper.

Tables I and II show the approximate cost of conduit lines and manholes. These prices will vary according to the price of labor and material, and are based on Chicago prices at the present time.

TABLE I.—APPROXIMATE COST OF LAYING SINGLE-DUCT CLAY CONDUIT (IN CENTS), PER DUCT FOOT.

Number of ducts.	Cost of Repaving, Per Square Yard.									
	$0.25	$0.50	$0.75	$1.00	$1.50	$2.00	$2.50	$3.00	$3.50	$4.00
2	24	29	31	34	38	43	47	52	56	61
4	22	25	26	27	30	33	35	38	41	43
6	20	22	23	24	26	28	30	32	34	36
9	19	21	22	22	24	25	27	28	30	31
12	19	20	21	21	23	24	25	26	28	29
16	18	19	19	20	21	22	23	24	25	26
20	17	18	19	19	20	21	22	22	23	24
24	17	18	18	18	19	20	21	21	22	23
30	16	17	17	17	18	19	19	20	21	21
40	16	17	17	17	18	18	19	19	20	20
50	16	16	16	17	17	18	18	19	19	20

These prices are based on 3 inches of concrete on all sides of conduit. Portland cement at $1.50. Tile to be laid by brick mason at 60 cents per hour. Top of concrete to be 30 inches below surface of street. Tile at five cents per duct foot.

It may be found impossible to obtain permission for opening the pavement on certain streets, or there may be insufficient room to build an ordinary conduit line, owing to obstructions. In such

TABLE II. COST OF MANHOLES, EXCLUSIVE OF COST OF REPAVEMENT.

MATERIAL.	*3'x3'x4' Quan	*3'x3'x4' Amt.	3'x4'x4' Quan	3'x4'x4' Amt.	4'x4'x4' Quan	4'x4'x4' Amt.	4'x5'x5' Quan	4'x5'x5' Amt.	5'x5'x5' Quan	5'x5'x5' Amt.	5'x5'x6' Quan	5'x5'x6' Amt.
Excavation and removal of dirt, at 87½c per cubic yard	3.70	$ 3.24	4 44	$ 3.88	8 00	$ 7.00	10.88	$ 9.52	12.70	$ 11 11	16.30	$ 14.26
Brickwork—Sides at $9 50 per cubic yard	1 67	15.86	1.89	17 95	2.11	20 04	2.92	27 74	3.19	30.30	4.17	39.62
Concrete—Bottom at $7 per cubic yard	..	.. ..	..	..	0 29	2.03	0.37	2.59	.46	3 22	.56	3 92
Concrete—Top at $8 per cubic yard	.56	4 48	0.67	5.36	0 84	6.72	.96	7 68	1 16	9 28	1 35	10 80
Iron in roof at 3c per lb	105 lb	3.15	184 lb	5 52	129 lb	3 87	129 lb	3 87	153 lb	4 59	153 lb	4 59
Sewer connection and permit at $25 each	....	.....	...	......	1	25.00	1	25.00	1	25.00	1	25.00
Trap and backwater valve at $6.50 each	.. ..	....	.....	......	1	6.50	1	6 50	1	6 50	1	6 50
Sewer grates at 30c each	.....	....	..	....		.30	.....	30	.....	.30	.....	.30
Frame and cover at $15 each	1	15.00	1	15 00	1	15 00	1	15 00	1	15.00	1	15 00
Supervision and incidentals	.....	2.25	....	2.25	.....	2 25	....	2 25	... .	2.25	.....	2 25
Totals	...	$43 98	.....	$47.92	.....	$ 88.71	.. .	$100.45	..	$107 55	.. .	$123 24
Square yards repaving required	4.00	.. ...	4.67	......	8.11	. ..	8.89	.	9 88	..	10 67	. .....

MATERIAL.	6'x6'x6' Quan	6'x6'x6' Amt.	6'x7'x6' Quan	6'x7'x6' Amt	6'x8'x6 Quan	6'x8'x6 Amt	7'x7'x6 Quan	7'x7'x6 Amt	*8'x8'x6 Quan	*8'x8'x6 Amt.
Excavation and removal of dirt, at 87½c per cubic yard	19 00	$ 16.63	21.33	$ 18.66	23 70	$ 20 74	24 00	$ 21.00	29.68	$ 25.96
Brickwork—Sides at $9 50 per cubic yard	4.50	42.75	4 83	45 88	5 17	49 11	5 17	49 12	5 83	55 39
Concrete—Bottom at $7 per cubic yard	.67	4 69	0 78	5 46	0 89	6 23	91	6 37	1 18	8 26
Concrete—Top at $8 per cubic yard	1 55	12 40	1 77	14 16	1 94	15 52	2 01	16 08	2 50	20 00
Iron in roof at 3c per lb	178 lb	5 34	178 lb	5 34	178 lb	5.34	215 lb	6 45	227 lb	6 81
Sewer connection and permit at $25 each	1	25 00	1	25 00	1	25 00	1	25 00	1	25 00
Trap and backwater valve at $6.50 each	1	6 50	1	6 50	1	6 50	1	6 50	1	6 50
Sewer grates at 30c each	.....	.30	....	.30	.....	.30	... .	30	. ..	.30
Frame and cover at $15 each	1	15.00	1	15.00	1	15 00	1	15 00	1	15 00
Supervision and incidentals	. ...	3.25	. ...	3 25	..	3 25	.	3 25	.	3 25
Totals	...	$132.06	. .	$139.55	. ..	$140 90	..	$149 07	..	$160 44
Square yards repaving required	12 00	.. ...	12 68	... .	13 68	. ....	13 89	..	16 00	. .....

*Last dimension is depth.

Depth of manhole given in the clear inside dimension.

cases it is desirable sometimes to build tunnels. These may be left as open tunnels with cables laid in racks, or tile may be laid closing up the tunnel, either entirely or partially, thus making a regular conduit line. This method might possibly be used to advantage for crossing crowded street intersections, or railway tracks, where it is difficult to make an open cut. Several hundred feet of these small tunnels have been built in Detroit, Mich. Tunnels under rivers make a much safer method of installing cables than submarine cables laid on the bottom of the river, although if there are only a small number of cables the cost of the tunnel would hardly be warranted.

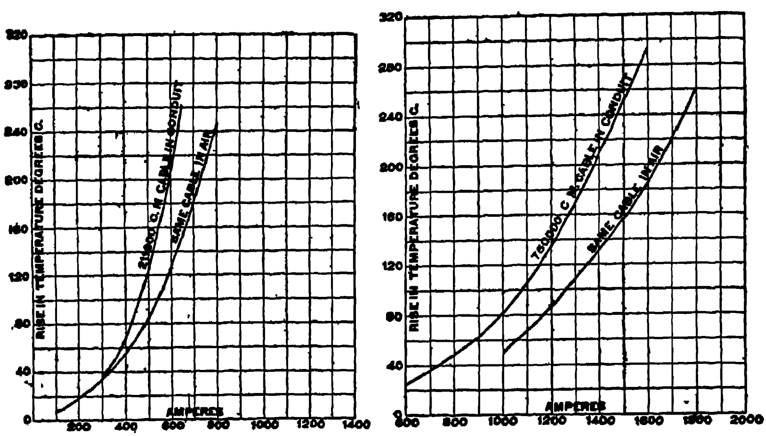
Cables.

Nearly all cables for underground work are insulated with either paper or rubber and are lead covered. For some purposes, such as the grounded side of street-railway circuits, or the neutral of Edison three-wire systems, bare copper is satisfactory. Bare copper should not, however, be installed in the same duct with lead-covered cables. Paper-insulated cable is more generally used than rubber, on account of its lower first cost and also on account of its greater carrying capacity. Rubber cable will stand rougher use and may be more easily handled in extremely cold weather than paper cable. It is easier to protect the ends of rubber cables than those of paper, and for this reason rubber cable is sometimes used for mains and services on account of the large number of connections necessary for this work. It is not difficult, however, to safely install paper-insulated cable for this class of work, and it is much more satisfactory to do this and thus carry only one kind of cable in stock. Paper-insulated cable is particularly suitable for feeders on account of its high carrying capacity. Within the past two years cable with varnished cambric insulation has been used for high-voltage work inside stations, and to a limited extent for underground work.

For low-tension work, up to 700 volts, the thickness of insulation on cables is determined largely by mechanical considerations. For street-railway feeders single-conductor cable is used, while for lighting and power lines either single, two- or three-conductor cable is used for distributing mains, but it is more difficult to make satisfactory joints for service taps on three-conductor cables than on single-conductor ones, particularly if this has to be done in small service handholes. Single-conductor cable makes a safer

installation for this class of work. Single-conductor cable is commonly used for low-tension feeders in sizes ranging from 350,000 to 1,000,000 cm. Considerable saving in feeders may be made by using two-conductor concentric cable with pressure wires laid up with the outer conductor. Concentric cables for feeders are used mostly in the 1,000,000 cm size. Its carrying capacity is less than that of two-conductor cables of the same size, and the cost is about the same. The saving is made in duct and manhole space and in the cost of installation.

Figs. 2, 3 and 4 show the carrying capacity of lead-covered paper-insulated cable in air and in conduit. These tests were made in a laboratory, the conduit consisting of a single duct of



FIGS. 2 AND 3. CARRYING CAPACITY OF LEAD-COVERED CABLE IN CONDUIT AND IN AIR.

vitrified clay pipe surrounded with approximately 6 inches of sand on all sides. Figs. 5 and 6 are the result of tests on 1,000,000 cm two-conductor concentric cable, the tests being made with the cable in the air.

The cables had a 6-32 in. inner paper tube, a 5-32 in. outer paper wall and a 4-32 in. lead wall. Fig. 5 shows curves indicating the rise in temperature and increase in resistance with increasing load. Fig. 6 refers to a constant current of 1000 amperes. Fig. 7 gives the results of tests of a 4-0 three-conductor cable in a conduit, made in cold weather, other cables in the conduit not being heavily loaded. The cable had a 6-32 in. paper wall over each conductor, a 4-32 in. wall over the three conductors and a 4-32 in.

lead outer wall. The curves show the relation between temperature and current. Fig. 8 gives curves referring to a similar test of a 1-0 cable having the same insulation dimensions.

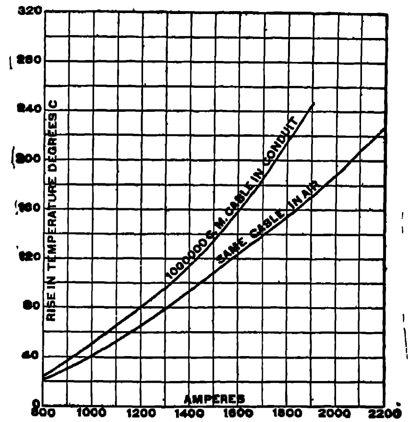
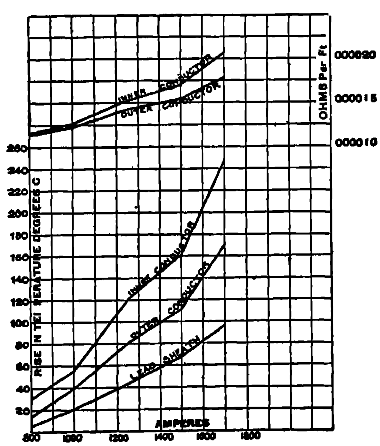
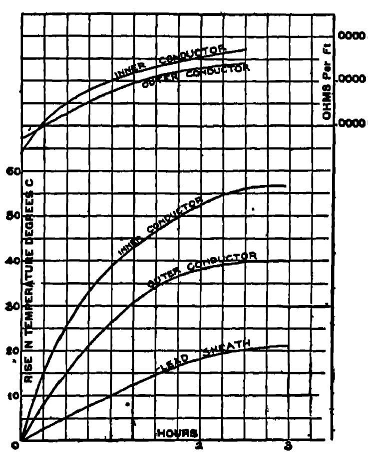


FIG. 4. CARRYING CAPACITY OF LEAD-COVERED CABLE IN CONDUIT AND IN AIR.

Concentric cable should be made with the inner conductor enough larger than the outer so that the average loss in the two conductors will be the same. At maximum load the loss would

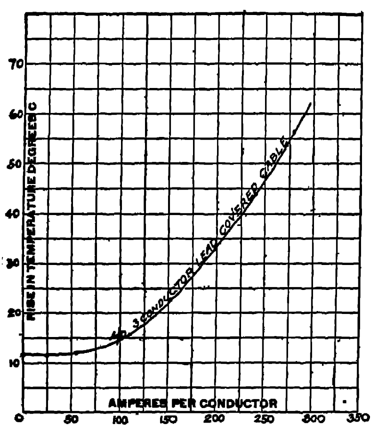




FIGS. 5 AND 6. CURVES OF CABLE TESTS.

be more in the inner than the outer conductor and less in case of light load.

Single- or multiple-conductor cables, up to four conductors, are used on alternating-current primary distribution lines. Duplex cables, with the wires laid side by side are sometimes used. This form of cable, with paper insulation, must be very carefully handled, as a slight bend edgewise is likely to crack the paper. If it is thought necessary to use this style of cable it should be purchased witth rubber insulation. It is not, however, a desirable form of cable, for the reason that two V-shaped openings are left between the lead and the insulation and there is danger of water finding its way into these openings when pulling the cable in



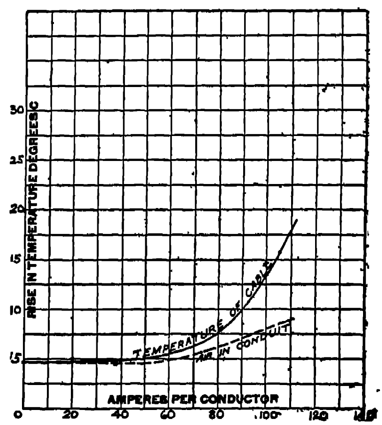


FIG. 7. TEST OF NO. 4-0 LEAD-COVERED, THREE-CONDUCTOR CABLE.

FIG. 8. TEST OF NO. 1-0 THREE-CONDUCTOR, LEAD-COVERED CABLE.

wet ducts. For two-wire work a concentric cable or two single-conductor cables is much safer than a duplex cable with the conductors side by side. Three- or four-conductor cables make up well and are easily installed. A three- or four-conductor cable admits of a split type of insulation, especially in cables with paper insulation; each conductor has the thickness of wrapping necessary to give the proper insulation between the conductors, and all of the conductors have a common wrapping, thus avoiding too much insulation between conductors in order to obtain a proper amount between conductors and ground.

Transmission lines for carrying large amounts of power from stations to sub-stations are nearly always three-conductor and made with the split type of insulation. Cables are in use in the United States and Canada carrying current at pressures as high as 25,000

volts, although a large part of cables in this class of work are operating at pressures between five and fifteen thousand volts. Table III shows the thickness of insulation used by the different companies on cables of this kind. It will be seen that for paper cables the thickness of insulation between conductors ranges from 17 to 67 mills per 1000 volts, and from 15 to 52 mills per 1000 volts between conductors and ground. In other words, some companies are using a factor of safety three or four times that used by others. Table IV gives weights and diameters of single-conductor paper and lead-covered cable.

TABLE III.—INSULATION USED BY DIFFERENT COMPANIES ON THREE-CONDUCTOR HIGH-TENSION CABLES.

COMPANY.	Line voltage.	Kinds of insulation.	Thickness of Insulation in Thousandths of an Inch.			
			Between conductors.	Between conductors and ground.	Per 1000 volts. Between conductors.	Per 1000 volts. Between conductors and ground.
New York Edison	6,600	Paper	312	312	47	47
New York Metropolitan	6,600	Paper	436	343	67	52
New York Sub. Co.	11,000	Paper	436	468	40	43
New York Manhattan	11,000	Paper	436	436	40	40
Buffalo-Niagara L.	11,000	Paper	406	406	37	37
Buffalo-Niagara L.	11,000	Rubber	562	281	51	25
Chicago-Edison	9,000	Paper	406	383	44	38
Milwaukee	15,000	Paper	500	437	33	29
St. Paul	25,000	Paper	562	484	22	19
St. Paul	25,000	Rubber	436	374	17	15
Providence	12,500	Rubber	562	281	45	22
Montreal	25,000	Paper	562	406	22	16

Installation of Cables.

As a rule more trouble will develop on underground cables due to poor work on installation, rather than to faults in the cables themselves. This is particularly true of the first few years the cables are in service. It will generally be found more satisfactory for a small company to have its cables installed by the manufacturing company which furnishes them; a large company, however, can install its own cables cheaper than the manufacturing company. All cables, excepting possibly those of small sizes, as well as those of a moderate size where a large amount is used, should be ordered in exact lengths, making the proper allowance for training in manholes and waste cable. Manholes should be located so that it will not be necessary to pull longer than 500-ft. lengths of cable, although in special cases this distance may be

TABLE IV. WEIGHTS AND DIAMETER OF SINGLE CONDUCTORS, PAPER AND LEAD-COVERED CABLE.

Size—B. & S. & Edison.	Thickness Paper.	DIAMETER IN INCHES, OVER					WEIGHTS IN LBS. PER FOOT.						
		Copper.	Paper.	Lead.			Copper.	Paper.	Lead Only.			Total, Copper, Paper, Lead.	
				1/16 in.	3/32 in.	4/32 in.			1/16 in.	3/32 in.	4/32 in.	Lead 3/32 in.	Lead 4/32 in.
14	3-32	.073	.260	.386	....	....	.014	.0301	.313	....	....	....	....
12	3-32	.092	.279	......	.467	....	.022	.0338	......	.544	....	.599	....
10	3-32	.116	.303	......	.491	....	.035	.0378	......	.579	....	.642	....
8	3-32	.147	.334	......	.522	....	.057	.0434	......	.624	....	.724	....
6	4-32	.180	.430	......	.617	....	.085	.0735	......	.763	....	.922	....
5	4-32	.209	.459	......	.646	....	.112	.0805	......	.806	....	.999	....
4	4-32	.234	.484	......	.671	....	.140	.0865	......	.842	....	1.069	....
3	4-32	.263	.513	......	.700	....	.178	.0935	......	.885	....	1.157	....
2	4-32	.295	.545	......	.732	....	.224	.1012	......	.931	....	1.256	....
1	4-32	.325	.575	......	.762	.825	.255	.1085	......	.975	1.358	1.338	1.722
0	4-32	.378	.628	......	.815	.678	.338	.1213	......	1.052	1.461	1.511	1.920
00	4-32	.425	.675	......	.862	.925	.426	.1326	......	1.122	1.552	1.681	2.111
000	4-32	.475	.725	......	.912	.975	.532	.1447	......	1.194	1.649	1.871	2.328
0000	4-32	.524	.774	......	.961	1.024	.650	.1565	......	1.265	1.744	2.072	2.551
200	4-32	.505	.755	......	.942	1.005	.614	.1519	......	1.237	1.707	2.003	2.473
250	4-32	.568	.818	......	....	1.068	.790	.1671	......	....	1.829	....	2.786
300	5-32	.637	.949	......	....	1.199	.949	.2113	......	....	2.083	....	3.243
350	5-32	.680	.992	......	....	1.242	1.092	.2249	......	....	2.167	....	3.484
400	5-32	.735	1.047	......	....	1.297	1.224	.2397	......	....	2.274	....	3.738
450	5-32	.777	1.089	......	....	1.339	1.343	.2510	......	....	2.355	....	3.949
500	5-32	.820	1.132	......	....	1.382	1.550	.2625	......	....	2.438	....	4.251
600	5-32	.900	1.212	......	....	1.462	1.874	.2841	......	....	2.594	....	4.752
750	5-32	1.020	1.332	......	....	1.582	2.331	.3163	......	....	2.826	....	5.473
800	5-32	1.037	1.349	......	....	1.599	2.462	.3209	......	....	2.859	....	5.642
900	5-32	1.096	1.408	......	....	1.658	2.815	.3368	......	....	2.974	....	6.126
1000	5-32	1.157	1.469	......	....	1.719	3.138	.3532	......	....	3.092	....	6.583
1250	5-32	1.296	1.608	......	....	1.858	3.831	.3906	......	....	3.362	....	7.584
1500	6-32	1.412	1.787	......	....	2.037	4.681	.5786	......	....	3.709	....	8.969
2000	6-32	1.652	2.027	......	....	2.277	6.237	.6653	......	....	4.175	....	11.077
2500	7-32	1.848	2.285	......	....	2.535	7.674	.8716	......	....	4.675	....	13.221

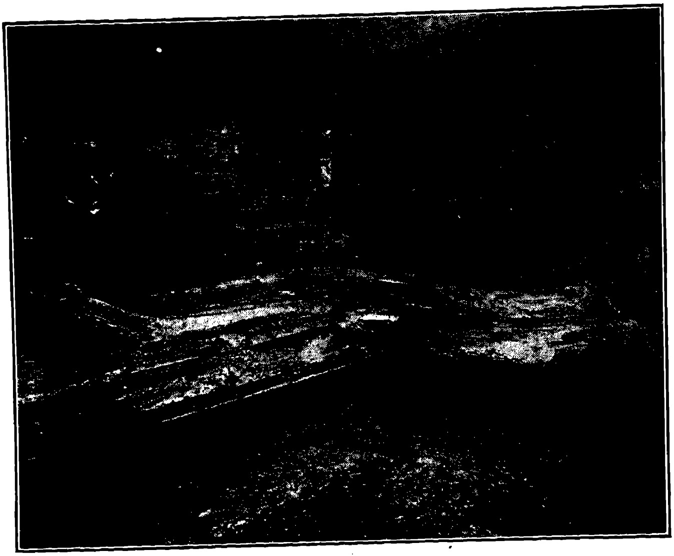


Fig. 9. Protecting Cables in Manholes with Split-Clay Tile.

Fig. 10. Terminal Bells on Ends of 9000-volt, Three-Conductor Cable.

extended slightly. Short lengths of small-sized cable may be easily pulled in by hand, but longer lengths or large cable will require a capstan, or some similar device, operated ordinarily either by men or by horse. Within the past two years electric trucks with a motor-driven winch have been used for drawing in cables and satisfactory reports from several companies using them have been received. It is claimed that there is a very decided saving in using the truck as compared with a capstan for drawing in cables. This method should be more satisfactory in a crowded street than the use of the capstan, as there would be less time lost owing to being interfered with by passing vehicles.

The ends of the cable should be examined as soon as the cable is pulled in, to determine if any moisture is present; if so, the cable should be cut back far enough to remove the moisture and the ends carefully taped. If any great length of time is to elapse before jointing, the lead should be wiped over the end of the cable. If manholes with square corners are used, care should be exercised to avoid bending the cable too short in order to make a good-looking installation. For work where a great deal of room is not required in manholes it is best to build them with the corners cut on the diagonal, so that the cables, on leaving the end of the duct, will follow the manhole wall easily without necessitating short bends.

Iron racks are used ordinarily for supporting cables, and while this is the easiest way of doing it, there is the danger of stray currents crossing from one cable to another where iron brackets are used. This may be avoided, however, by putting small pieces of sheet rubber on top of the iron brackets. Manholes are sometimes built with chases in the side wall to provide support for the cables. This also serves the purpose of protecting the cables from fire due to adjoining cables. The third method of supporting cables, and also at the same time fireproofing them, is the use of split clay tile for covering the cables, the tile being supported on one or two light angle irons extending longitudinally through the manhole. At the ends of the manhole 45-deg. curves are laid in reverse, so that cables are completely covered with tile through the manhole. This method is the safest one of the three and the most expensive. Its use is, however, warranted in protecting the important lines, such as high-tension transmission cables. Fig. 9 shows a manhole where split tile has been used for covering the cables. Cables may also be fireproofed by covering them

with a double wrapping of asbestos paper or tape, and binding this by means of brass or iron tape. This fireproofing is more easily installed than the split-clay tile, particularly in crowded manholes.

Special attention should be given the taking care of station ends of cable, particularly three-conductor transmission cables. Fig. 10 shows the ends of four 9,000-volt three-conductor cables protected with the necessary terminal bells.

Apparatus in Manholes Other Than Cables.

On a low-tension system employing an interconnected network of mains it is necessary to install junction boxes at the street intersections, so that the feeders and mains may be disconnected in case of trouble, either automatically, by fuses blowing, or by removing the fuses by hand. It is necessary that these boxes be water-tight and still be easily accessible. Cast-iron boxes are used with suitable bus bars and cable terminals, the cable being brought in through the sides or bottom of the box and the holes around the cables being made water-tight, either by means of stuffing boxes or wiped connections. A view of such a box installed in a manhole is shown in Fig. 11. These boxes are ordinarily made six-pole and two-way, the neutral connection of the three-wire system being omitted from the junction box. A rubber gasket is used to make a water-tight joint at the door. Junction boxes have been built for installation in the roof of the manhole so that it is possible to get at the connections readily from the surface of the street in the same manner as in the Edison junction boxes for tube work. Service boxes are sometimes installed in manholes, but it is usually better to place them on the curb wall in the basement of the customers' premises.

Transformers for manhole use should be built with a water-tight case. Primary fuse boxes should not be places in manholes unless it is absolutely certain that the manholes can be kept dry. If an interconnected network of secondaries is used, junction boxes should be installed and connections from the secondaries of the transformer carried to the junction box.

Connections Between Overhead and Underground Lines.

In an alternating-current system operating both overhead and underground lines one of the most difficult places to protect is the connections between the two. This is ordinarily done by carrying

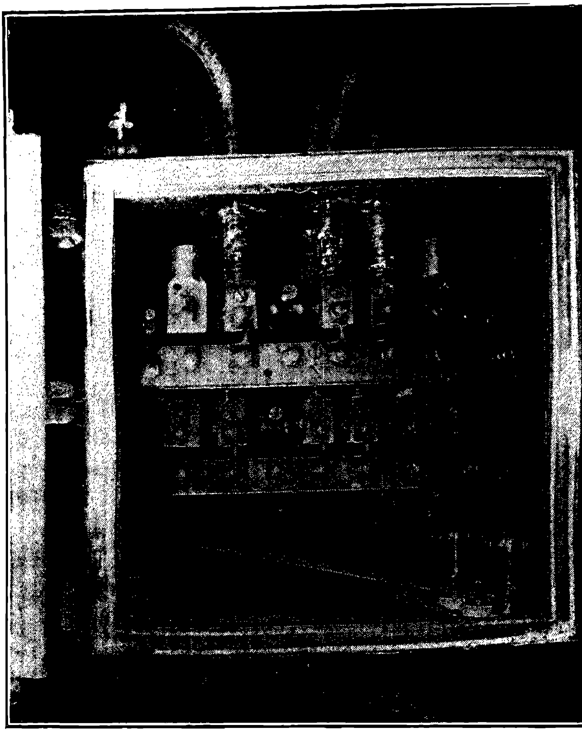


FIG. 11. TAILLEUR JUNCTION BOX.

FIG. 12. CABLE POLE CONNECTING OVERHEAD AND UNDERGROUND LINES.

a lead covered cable up the pole in an iron pipe to within a few feet of the cross arms. The end of the lead cable should be protected with a suitable pothead and the connections made from the lead cable to the weatherproof wire by means of a short piece of wire with high-grade insulation. Varnished cambric-insulated wire with an additional protection against the weather of two or three layers of friction tape, well painted, has been used for this purpose. It is well also to box in the lead-covered cables above the top of the iron pipe, taking the insulated wires out through bushings in the sides of the box. The boxing in of the lead cable and potheads is done both to protect them from the weather and from damage by linemen, and also to protect the linemen from coming in contact with the grounded lead while working on live wires.

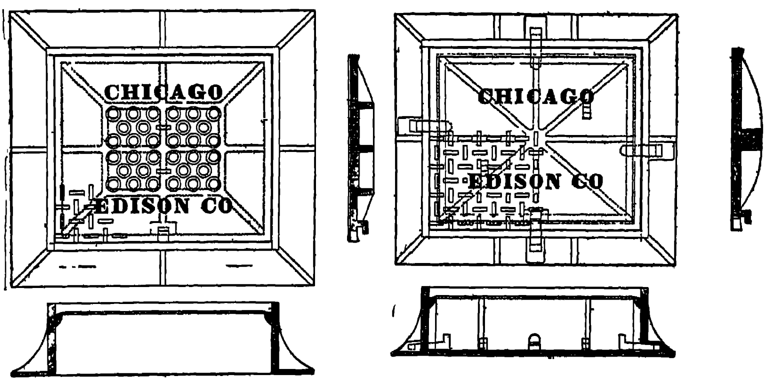


FIG. 13. MANHOLE FRAMES AND COVERS.

A view of cable pole with the connections made in this manner is shown in Fig. 12. Underground cables should be protected against lightning discharge by means of arresters placed within one or two poles of the cable pole.

VENTILATION OF MANHOLES.

On large underground systems it is desirable to ventilate the manholes for the purpose of allowing heat given off by the cables to escape. The amount of heat given off by a large number of loaded cables is very considerable, and while this heat is given off to the surrounding earth to a great extent, more of it can also be gotten rid of by ventilating the manholes. This is done ordinarily by leaving a sufficient number of openings in the cast-iron covers of the manholes. A manhole frame and cover of this type is shown in Fig. 13. It may sometimes be necessary to use arti-

ficial ventilation for manholes where the heat given off by the cables is not sufficiently dissipated in the surrounding earth and by the manhole ventilation; this, however, would only be necessary in case of very large and heavily loaded lines. All ventilated manholes should have sewer connections. Ventilated manholes are a great help in allowing gas to escape from conduit lines and from the ground generally in their vicinity. On comparatively small conduit lines, also on small service manholes or handholes and on manholes located where sewer connections can not be made, closed manhole covers should be used. These manhole covers are usually made of a double construction, the inner cover having a

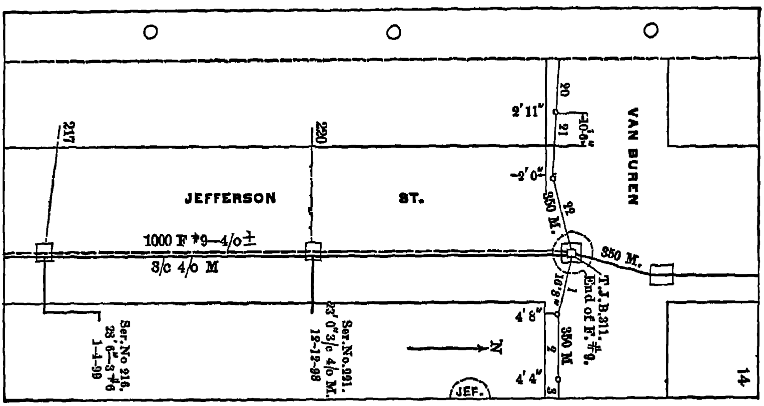


FIG. 15. SYSTEM OF RECORDS, UNDERGROUND LINES.

rubber gasket and being held tight against the rubber gasket by means of iron wedges or similar devices. Fig. 14 shows a closed frame and cover.

RECORDS.

One of the most essential things in connection with an underground system is a satisfactory system of records. Suitable forms should be provided so that it will be an easy matter for the foreman on the work to make the necessary notes, and these foreman's reports should be sent to the draughting room for transferral to the permanent records. The number of records necessary will depend on the size of the company and the nature of the work. Some of the records kept by a large company are shown in Figs. 15, 16 and 17. A good system of records will be found of great value in locating and taking care of trouble and in laying out new

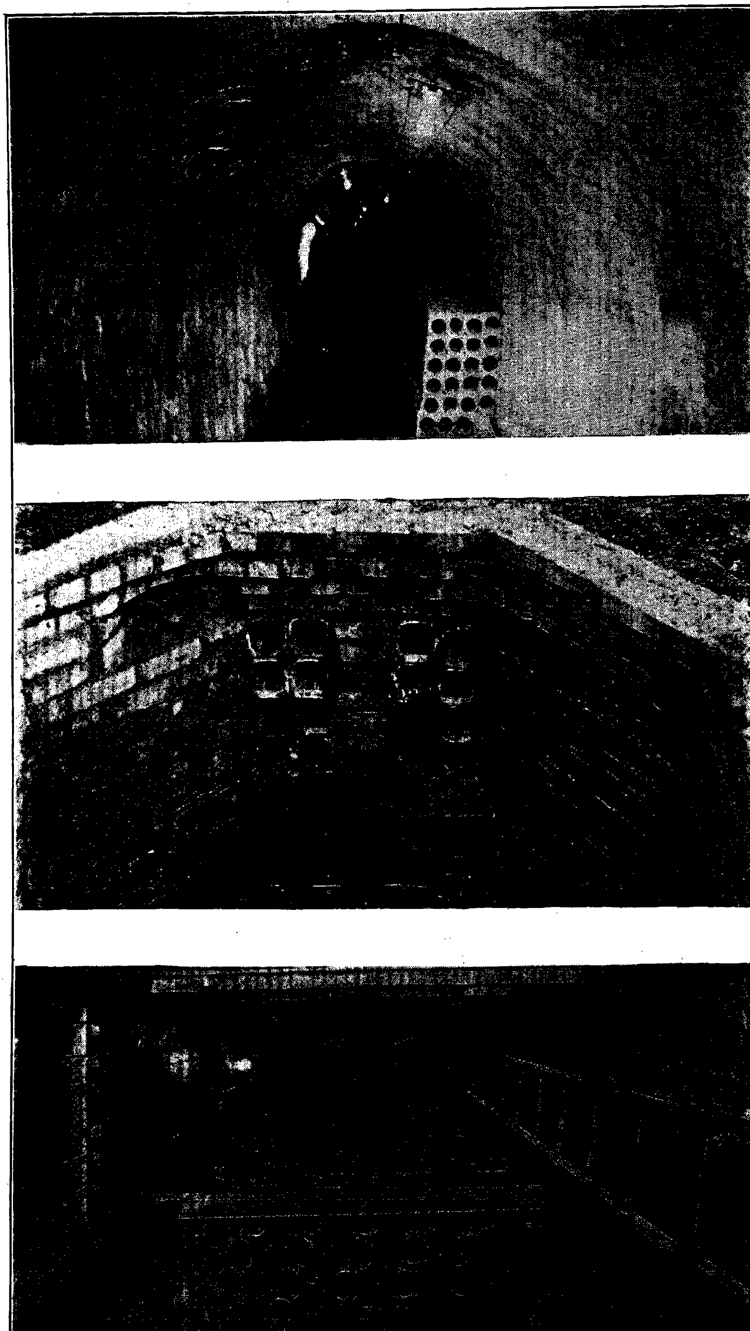


FIG. 14. UNDERGROUND CONDUITS.

work. They will also be of assistance to the contract department in looking up new business. It frequently happens, where com-

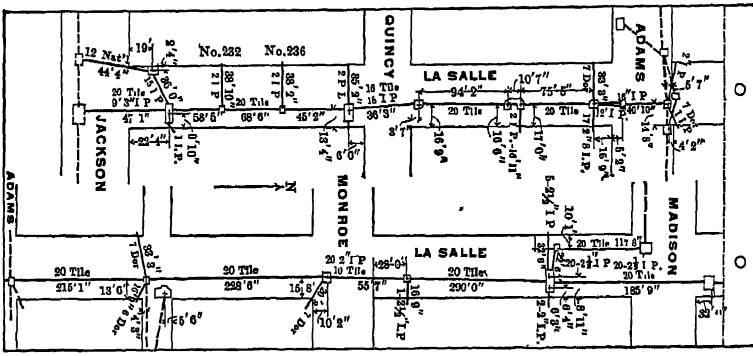


FIG. 16. SYSTEM OF CONDUIT RECORDS.

plete records are not kept, that the company depends to a certain extent upon the memory of some of the employees, and if these

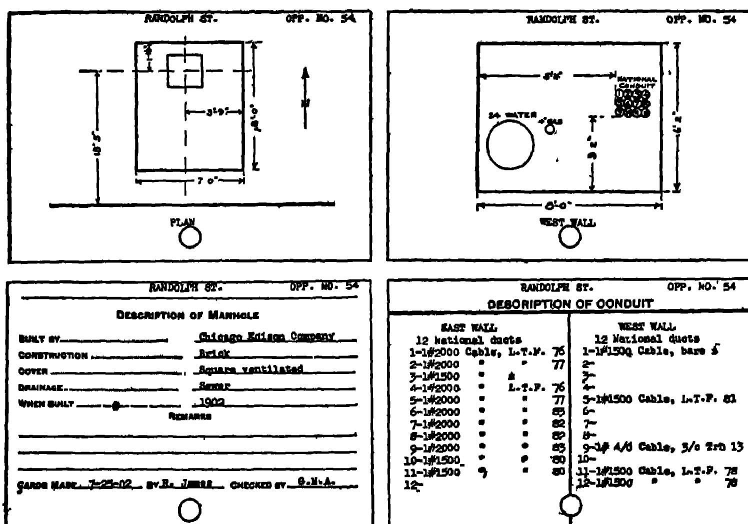


FIG. 17. SYSTEM OF MANHOLE RECORDS.

employees leave the company, the information is lost. For a comparatively small expense records can be made which will be always accessible.

Operations of Underground Systems.

Underground lines require much less attention than overhead ones, but it is a mistake to suppose that when lines are once underground they will take care of themselves. There is always a chance for trouble. Manholes should be cleaned at reasonable intervals and at the time the cleaning is done an inspection should be made to determine if there are any signs of trouble on the cables due to burnouts, electrolysis or other causes. If the cables in the manholes have been covered with tile, no inspection is needed, but there will be a great many places where there are exposed cables. Junction boxes should be opened and the contact services under fuses cleaned. Tests should also be made for continuity on all lines running from one junction box to another. The cable lugs on the junction boxes should also be examined for signs of heat. If a large number of loaded cables pass through one manhole it is well to have temperature readings in manhole taken to determine whether a temperature unsafe for the cables is reached; these can be taken either by a recording thermometer or one giving maximum temperature. In cold weather, or when the streets are muddy, it will pay to have an inspector go over heavily loaded conduit lines to make sure that the ventilating holes in the manhole covers are open. The feeder readings, taken in stations and substations, should be carefully followed up to make sure that no feeders are overloaded and the load on the mains should be kept track of as far as possible. This is difficult to do except in a general way. Insulation resistances on low-tension lines are not of much value, as far as the cables themselves are concerned, for the reason that the surface leakage around the terminals of the cables will generally give low resistance. On high-tension cables insulation tests are of more value than on low-tension ones. On important high-tension lines, such as transmission lines carrying large amounts of power, it is well to test the cables periodically at voltages 50 per cent higher than normal.

Method of Locating Grounds on Underground Cables.

Where one conductor of a multiple-conductor cable is grounded and another conductor is clear the following adaptation of the loop test can be used to advantage. This method also applies to single-conductor cable where another conductor is available for the return. The two conductors must be of the same size or corrections will

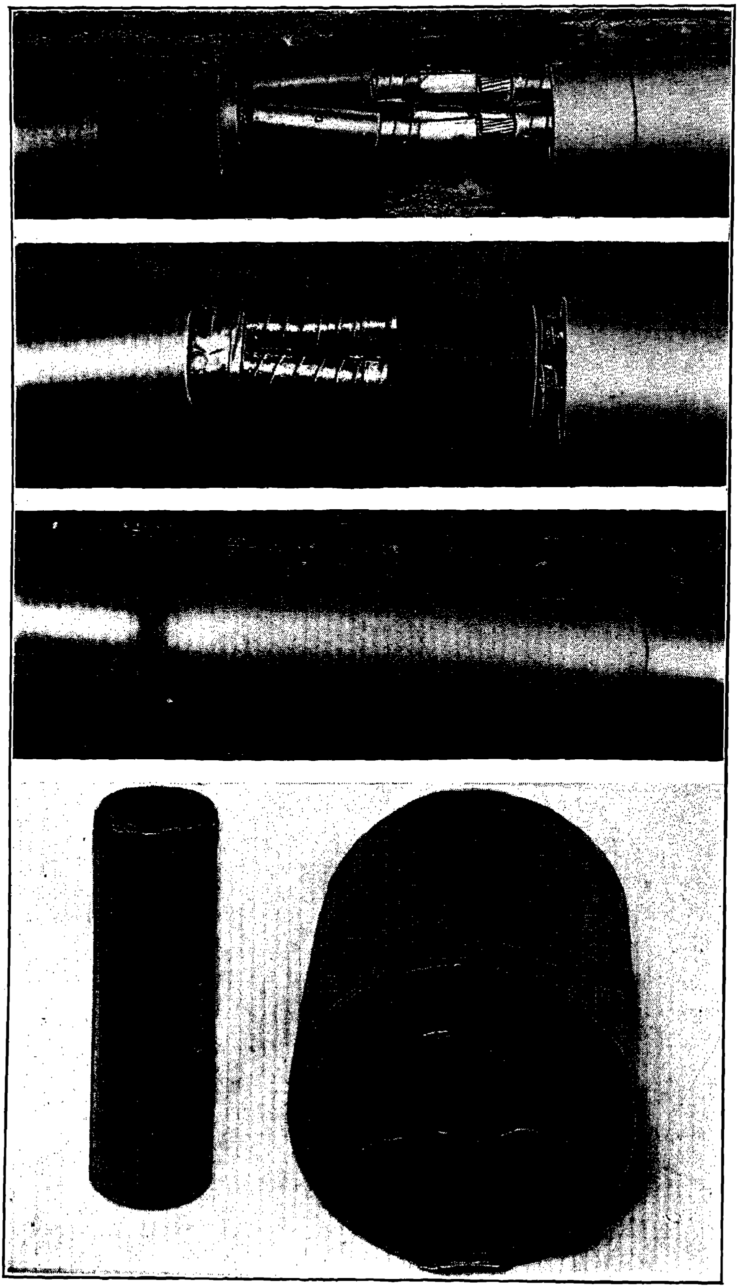


FIG. 19. METHOD OF MAKING A JOINT ON A THREE-CONDUCTOR CABLE FOR HIGH-VOLTAGE WORK.

have to be made for the difference in the resistance of the two sizes.

The grounded conductor is joined to the good conductor at the opposite end from which the test is to be made. A resistance wire is used, made up in the form of a straight wire bridge or wound on a threaded drum. The wire is calibrated throughout its length. Contact C referring to Fig. 18, is arranged so that it can be moved along the resistance wire throughout its entire length. A battery is connected between the contact C and ground and a galvanometer between the terminals A and B. In making tests, C is set preferably at the middle point of the resistance to start with. When contact is made, the galvanometer will swing to either one side or the other, depending on the location of the ground. Contact C is then moved along the resistance wire until no deflection is obtained upon the galvanometer. It will be evident that the distance to A to C of the resistance wire will repre-

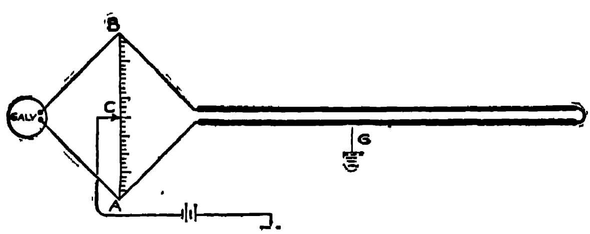


FIG. 18. METHOD OF LOCATING GROUNDS.

sent the distance from A to G on the conductor which is grounded.

This can be represented by the following formula, wherein L represents the total length of the conductors joined together, and AC and BC represents the relative distance measured on the resistance arm:

$$(1)\ \frac{A\,C}{B\,C} = \frac{A\,G}{B\,G};\ or\ \frac{A\,C}{B\,C} = \frac{A\,G}{L—A\,G}.\ Solving, A\,G = \frac{A\,C\ (L—A\,G)}{C\,B}$$

L may be expressed as the length of the conductor in feet where the two conductors which are joined together are of the same size or as the resistance of the conductors where the conductors are made up of two or more different sizes of cable. It will be noted that this test is independent of the resistance of the fault. The resistance of the fault should be low enough to permit a sufficient

amount of current flow to allow satisfactory indication upon the galvanometer.

A convenient galvanometer for this work is one of the portable type made by the Western Instrument Company, with the zero in the center of scale and a deflection of five divisions each way.

This loop test has been found very satisfactory and on lines ranging from one to five miles in length the trouble is usually located within one or two hundred feet, and as trouble of this kind usually comes in manholes this means that it is located exactly.

In case the conductor on which the ground occurs is entirely burned in two and the insulation at the point at which cable is damaged is sufficient to withstand 1000 volts or more, the ground can be readily located by measuring the relative charging current from each end of the cable.

Fig. 19 illustrates the method of making up a joint on a three-conductor cable for high-voltage work. The lower part of the figure illustrates the paper tube used in jointing. These tubes are impregnated with an insulating compound before being used.

CONCLUSION.

During the past ten years the principal advancements in underground electrical construction have been the substitution of cable and conduit for Edison tubes, the more general use of paper-insulated cable as compared with rubber, the manufacture and installation of cables for extremely high voltages, the doing away with wood pump log and other inflammable material for conduit work, and a more stable character of construction in general.

The next ten years will probably see underground cables working at much higher voltages than those now used, possibly different material used for insulation purposes, better methods of protecting underground cables and safer construction.

DISCUSSION.

MR. ARTHUR WILLIAMS: I ask Mr. Ferguson what rule governs the location of street mains through narrow streets; that is to say, placing street mains on both sides of the street, the street being narrow, in a territory at present unimportant, but which may develop in the future.

MR. C. D. TAITE: Mr. Ferguson does not appear to differentiate in his paper between cables used as feeders and cables used purely as distributors. In England it is customary, if a drawing-in system is used, to separate the distributors entirely from the feeders. The drawing-in system is used for the feeders, but the cables for the distributors are soldered and

laid in antimonic paint in wood boxes. I should be glad to know whether that has been attempted in America to any extent. Mr. Ferguson has not referred to fibre conduits. A fibre conduit is now being introduced in England which is stated to be used fairly largely in the States.

Mr. P. S. Sheardown: I desire to ask a few questions from the writer of this paper. The question of underground mains is one of great importance, and yet we usually hear very little about them. The underground mains take the place of the veins and arteries in the human system, and it is most important, if we are to have a reliable supply of current, that they should be carefully guarded and looked after. We receive a great many suggestions regarding power stations, the care of lamps, etc.; but very often, when cables are once installed, they are left to take care of themselves, and careful records are not kept of the troubles which occur in conjunction with the cables and mains. One point raised was the question of cement-lined ducts, which have been pretty largely used in the United States. I ask if there is much trouble from electrolysis or other deterioration of the lead sheath of the cable in the use of these ducts? My experience is that cement is a bad substance to bring in contact with lead. Lead is not attacked by acids, and people therefore imagine that it is a metal which is hard to destroy; but while it is not destroyed by acids, it is easily attacked by other substances and it is hard to get your cement actually neutral. I want to ask about the electrolysis of the lead when laid in ducts. Some time ago I know it was the idea you could not have much trouble as long as you kept the difference of potential between the lead sheath and the duct, or rails or water pipes, below two volts. As a matter of fact, you get deteriorating action with less voltage than that in countries where the soil is damp. I have known cases where the voltage is not more than two-tenths of a volt above that of the general potential of the surrounding conductor, such as water pipes or wires, and yet there has been trouble that was at all events helped by electrolysis. I have made many tests on this matter, and it is most interesting to notice the way that water-courses, etc., alter the potential with regard to the theoretical potential that we should expect from a certain system. I think much might be done to avoid this trouble of electrolysis by the judicious bonding of the lead sheathing to the surrounding conductors such as rails, gas and water pipes, etc. If you do not bond at all, you will find at the outlying districts that the lead sheathing is usually negative to the track rails and positive to the surrounding water pipe system, but in the neighborhood of the return feeder cables the lead sheathing is negative to the water pipes and positive to the track rails, and it is some times possible to have electrolysis at either end. At the distant ends the trouble may be due to the sheathing being positive to the water and at the return feeder points due to it being positive to the rails. If you bond the sheathing to the rails all along, you will do away with any trouble due to electrolysis near the return feeding points, but by bonding to the rails at the outlying ends of the system you will probably make your lead at these points still more positive to the neighboring system of water and other pipes. The proper method to me appears to be when the system has just got running, to carefully test the relative potential between rails, lead

sheathing and underground pipes and to bond the lead sheathing to the rails wherever it is positive to them, and leave it unbonded where it is negative to the rails, which under ordinary circumstances will be in the outlying districts. If one could get permission to do so, it would be wise at these places where the lead is positive to the surrounding water pipes to bond them to the latter. I believe by adopting this method, in most cases the minimum of trouble due to electrolysis will be experienced. With regard to the ventilation of manholes, the method of simply leaving the holes in the removable manhole covers is in some ways an objectionable method. First of all these holes often get stopped up with hard mud, and secondly I have known of places where there has been trouble due to the caulks of horses' shoes getting into the holes and either pulling off the cover or damaging the animal's foot. This matter of providing an efficient ventilation for an underground system, having many manholes, is not as easily solved as might be expected.

Col. R. E. B. CROMPTON: The following questions arise on Mr. Ferguson's valuable paper. On page 678 he refers to the desirability of carefully made connections between overhead and underground lines. I think, however, that the apparatus he describes is not sufficient for such a difficult case as I have met with in Calcutta. In this town I have approximately forty miles of overhead and forty miles of underground mains. We were much troubled with lightning discharges, which frequently perforated the insulation of the underground mains. We tried every known kind of lightning arrester on the overhead lines. I will not here discuss the causes of these mysterious perforations, further than to suggest that it was possible that they were due to excessive static charges induced in the dielectric of the underground mains by charges of opposite sign produced in the very perfectly insulated overhead mains, but whatever was the cause of the trouble it was necessary to afford means of rapidly and completely separating the overhead from the underground system. On account of the annual torrential rains which in Calcutta continue during the months of July and August, I found it necessary that all the junctions should be brought into connecting boxes standing about five feet above the surface of the ground, with doors and covers so arranged that access could be given to all the connections even whilst it was raining and without the rain driving in on to the insulated terminals. Since we have used these pillar connection boxes we have found our work much facilitated. On the question of ventilating manholes I agree with Mr. Sheardown that the devices shown on page 679 would hardly suit us in England. We have a good many troubles and accidents in England due to gas escape, and all kinds of devices to cope with this. In some cases we have gone so far as to fill up all the spaces in the manholes or in the connecting boxes in which it is possible for gas to accumulate, but of course thorough ventilation is far better than these last devices which are inconvenient and costly. Personally I prefer ventilation by means of a draught induced by a vertical rising pipe carried from the box and fixed against the side of the nearest house. I wish also to call attention to page 682. I agree with what Mr. Ferguson says there as to the desirability of carefully inspecting the underground mains. I believe one cause why the supply company with which I

am connected in London has always paid good dividends has been that we have never neglected our mains. Our chief engineer insists upon a definite section of the mains being thoroughly overhauled each year; so that in the course of three or four years the whole system has been inspected, overhauled, and, if necessary, repaired. It may be of interest to you to know that a considerable portion of the mains I refer to have been laid down on a system which has everywhere been completely successful and I cannot understand now that the patent rights are expired that it has not been more universally adopted. Perhaps it is on account of the opposition of the makers of insulated cables. Seventeen years ago, we commenced laying down our three-wire network and a considerable portion of our feeders in the form of bare copper strip, this copper being strained over carefully designed porcelain insulators pinned on cross-bars in shallow culverts placed immediately beneath the footways. The insulators are at a considerable distance apart, this distance being practically the width of the two adjoining houses which face the mains. At each insulator, a manhole is fixed so that by taking up its cover the insulator can be cleaned and examined. At the same point the connections are made to the house circuits. In this way an extremely durable and easily maintained distribution system has been provided and the upkeep of it is practically confined to the cost of inspection and cleaning every three or four years. Within two or three years of the commencement of the system it was largely extended in London, Manchester, Edinburgh and other towns so that I believe upwards of 300 miles of it are in use and in every case it has given complete satisfaction.

Mr. FERGUSON: In answer to Mr. Williams's question, as to what we do in narrow streets — Chicago has not the misfortune which is experienced in New York and Boston, and some of the other old eastern cities, of having some very narrow streets, and so we do not meet the same difficulties that exist there. All of our streets are very wide, about sixty feet. We do not have the difficulty to which Mr. Williams referred. In our residence districts, however, we follow the practice of running our mains and feeders in many cases down the alleyways, so that the service is taken in from the rear of the property to the house, which may be located seventy-five or eighty feet from the alleyway. In that way we have only one set of mains for the service in two streets fronts; that is, the set of mains supplies the current to the left-hand side of one street, and the right-hand side of the other street.

Mr. Taite asked a question about the difference between feeders and mains. I will say that where cable feeders and mains are laid, it is the practice to put the feeders on the lower line of ducts and the mains on the upper line of ducts. The feeders go straight through from manhole to manhole and the mains may stop at any intermediate point in the blocks, in subsidiary manholes, and in that way the service is taken from the mains. We also make a difference between feeders and mains, in the use of cables for feeders and Edison tubes for mains, in that way the feeders run from manhole to manhole, for in the manhole is located one of the junction boxes described in the paper, and the Edison tubes which run

close to the curb are connected to this junction box, so that the service is taken off from the Edison tube in the regular way.

In regard to the use of fibre conduits, I have no personal experience regarding them. I think the American Fibre Conduit Company sold quite a little of this conduit, especially to the telephone companies, and I think to some of the electric light companies; and my only knowledge of it is based on observation, and not experience, and my objection to it is simply the possibility of damage owing to fire.

Regarding the cement deterioriating the cable, I have no personal experience regarding this. So far as I know we have not met with any such experience in this country. I will say, however, that there has been some trouble with cement-lined pipe, which is different from the ordinary cement conduit. There the trouble occurs at the ends, where there is a little iron ferrule.

Regarding the protection of the lead in ducts, ten years ago perhaps we used a jute covering on the lead cable, but I think all companies have abandoned it and do not use it any more. The objection to it is that with it there is difficulty in removing the cables from the ducts, because the cables stick together and adhere to the ducts.

(CHAIRMAN LIEB presiding.)

CHAIRMAN LIEB — To-morrow, Wednesday, there will be no session of this Section. There will be a joint meeting of Section F of the Congress, the Institution of Electrical Engineers of Great Britain and the American Institute of Electrical Engineers, which will be held at Festival Hall at 10 o'clock to-morrow.

We will now adjourn until 9:30 o'clock on Thursday morning.

THURSDAY MORNING SESSION, SEPTEMBER 15.

CHAIRMAN LIEB called the meeting to order at 9:30 a. m.

CHAIRMAN LIEB: The papers for this morning begin with a presentation of a paper by Prof. Clarence Feldman and Josef Herzog on "The Distribution of Voltage and Current in Closed Conducting Networks." As you have this paper in hand, gentlemen, I think it will be evident that it is hardly a paper on which much discussion can be had offhand, as it is a paper which treats with the problem from an analytical, graphical and mathematical standpoint. If it meets with your approval, we will consider this paper as having been read by title and we will then proceed with a discussion of the paper.

THE DISTRIBUTION OF VOLTAGE AND CURRENT IN CLOSED CONDUCTING NET-WORKS.

BY PROF. CLARENCE FELDMANN AND JOSEF HERZOG.

The principle of finding the distribution of voltage and current in closed conducting net-works was long ago taught by Gauss, Kirchhoff, Maxwell and others. But when electrical engineers felt the necessity of a simple way of handling these problems, especially for underground net-works of central stations in cities, it was found that the general solution and knowledge was not immediately applicable, and sufficient for the special technical demands of practice. The case was analogous to one in mechanics where it was necessary for the complete understanding and the

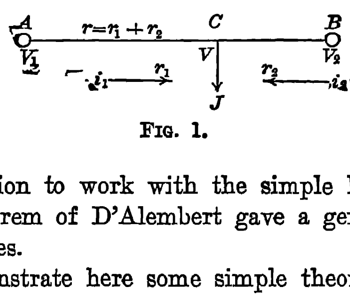


FIG. 1.

practical application to work with the simple laws of the lever, although the theorem of D'Alembert gave a general rule for the balancing of forces.

We shall demonstrate here some simple theorems which go to explain the manner of dealing with net-works of conductors from the standpoint of the electrical engineer, greatly restricting the application of mathematics.

1. DISCHARGING DOUBLE AND MULTIPLE KNOTS from the currents with which they are loaded.

Let $A\ B$ in Fig. 1 represent a conductor of a net-work whose end knots have the potential V_1 and V_2 and from which a current I is tapped at the point C with a potential V. Let the resistance of the whole conductor be r, and the resistances of the parts r_1 and r_2. Let the currents in these parts of the conductor be i_1 and i_2 and

assume ohmic resistances for the practical case. Then to have the balance in the current distribution

$$I = i_1 + i_2.$$

Furthermore, the potentials must correspond to the equation

$$V = V_1 - i_1 r_1 = V_2 - i_2 r_2,$$

and hence the currents in the conductor must be

$$i_1 = I\frac{r_2}{r} + \frac{V_1 - V_2}{r} \;;\quad i_2 = I\frac{r_1}{r} - \frac{V_1 - V_2}{r} \ldots\ldots\ (\text{I.})$$

Here the first members represent those currents which would flow in the conductor $A\,B$ if the potentials in A and B were equal, or if these points coincided. The second members represent the currents which would flow from A to B if the conductor had no load at all, and, therefore, the current might be called the *no-load current* of the line. If we interpret $I\,\frac{r^1}{r}$ and $I\,\frac{r^2}{r}$ as the *components* of the current I, we may regard them as acting at, or being tapped from, the points A and B without producing any change in the conditions of the net-work beyond the conductor $A\,B$.[1] If R represent the resistance of r_1 and r_2 in parallel, or $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$, these component currents may be written in the form $I\,\frac{R}{r_1}$ or $I\,\frac{R}{r_2}$ respectively, which admits at once of application to multiple knots.

Equation I shows that the final current distribution may be regarded as the *superposition* of two partial distributions (Strombilder), one with load and equal potentials, the other with no load and unequal potentials. In the same way the partial distributions of voltage or current may be superposed in whole net-works if different voltages or current-consuming devices be applied successively. This very important principle of superposition is expressed by the linear character of the equations. It is due to Smassen, Helmholtz and others, and its complete understanding opens a clear insight into the problems with which we here deal.

1. J. Herzog, Die Stromverteilung in Leitungsnetzen. *Electrotechn. Zeitschr.* Jan. 6, 1893.

The theorem of the *component* currents remains the same for multiple knots, for instance, for threefold knots. Fig. 2 shows

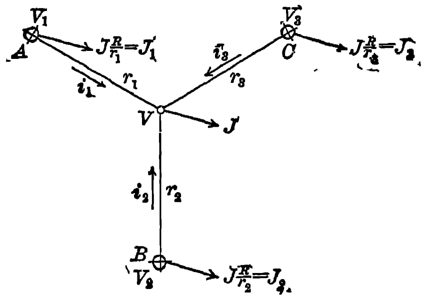


FIG. 2.

this case with the notations used. The partial currents are

$$I_1 = \frac{V_1 - V}{r_1} \qquad I_2 = \frac{V_1 - V}{r_2} \qquad I_3 = \frac{V_1 - V}{r_3}$$

and the consumer receives the current

$$I = \frac{V_1 - V}{r_1} + \frac{V_2 - V}{r_2} + \frac{V_3 - V}{r_3}$$

$$= \frac{V_1}{r_1} + \frac{V_2}{r_2} + \frac{V_3}{r_3} - V\left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}\right).$$

If R is the resistance resulting from the paralleling of r_1, r_2 and r_3, the potential at the threefold knot V, is

$$V = \left[\frac{V_1}{r_1} + \frac{V_2}{r_2} + \frac{V_3}{r_3} - I\right]R.$$

If we substitute this value in $I_1 = \dfrac{V_1 - V}{r_1}$, we obtain

$$I_1 = \frac{V_1}{r_1} - \frac{R}{r_1}\left(\sum_1^3 \frac{V_n}{r_n}\right) + I\frac{R}{r_1} = i_1 + I\frac{R}{r_1} \ldots\ldots (\text{II}.)$$

The currents I_1, I_2 and I_3 consist each of a no-load current i_1, i_2 and i_3, which depends only upon the potentials in A, B, C and the resistances r_1, r_2 and r_3, and of a component current $I\dfrac{R}{r_1}, I\dfrac{R}{r_2}, I\dfrac{R}{r}$ which values are only regulated by the current tapped from the center knot and the resistances of the legs and are independent

of the potentials of the knots. Therefore, the currents which are the components of the knot in the middle of the star may be carried away from this knot and thrown on the knots *A, B, C* without altering their potentials. In the same way we may carry the load from an n-fold knot to its neighboring knots by loading them with the corresponding component currents.[2]

2. TRANSFORMATION OF NET-WORKS INTO OTHERS WITH EQUIVALENT RESISTANCES, OR TRANSFIGURATION. (Widerstandstreue Transfiguration.)

The transformation of net-works or their parts in such a manner that the current and voltage distribution in the rest of the net-work

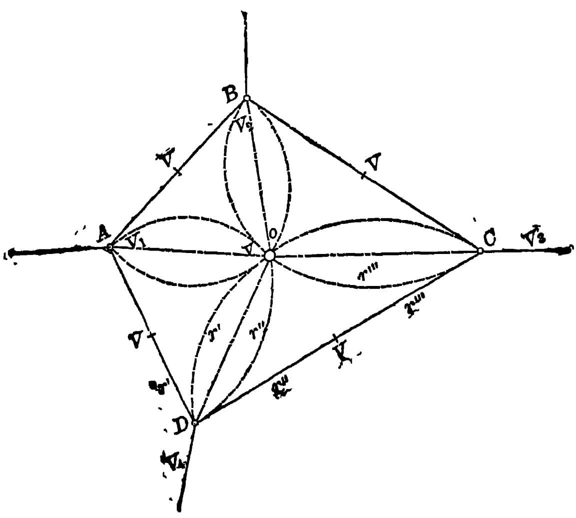


FIG. 3.

remains unaltered is a valuable means of studying net-works. Oliver Heaviside says in his "Electromagnetic Theory," "The method of resistance operators is applied to obtain the solutions in those cases in which any arrangement of resistances, inductances or capacities is inserted between the source of the electrical energy." Indeed, an investigation of the relations of resistances of parts of a net-work is exceedingly fertile. If we want to transform a resistance-polygon *A B C . . .* Fig. 3, into a star connection *O* in

2. Prof. J. Teichmueller has lately designated this theorem, which is ours, as new. *Electrotechn. Zeitschr.* April 30, 1903. Page 339.

such a way that no change of current or potential distribution takes place outside the polygon, we may locate in each conductor $A\ B, B\ C$ . . . a point with the potential V, of the knot O which we desire to form, and then we may connect these equivalent points so that they coincide. If we now replace adjoining resistances by an equivalent part, we obtain the star connection of equivalent resistance. If this idea is carried out for any given polygon,[3] it will be seen that the resistances of the newly formed legs of the star always depend upon the potentials of the knots $A\ B\ C$ . . ., and we find that only a triangle has the valuable property of admitting a transformation independent of these potentials, which transformation has been given by Dr. A. E. Kennelly.[4]

In order to be able to replace two parts of a net-work for the same knots, $A\ B\ C\ D$ . . . and the same potentials, V_1, V_2, V_3, V_4

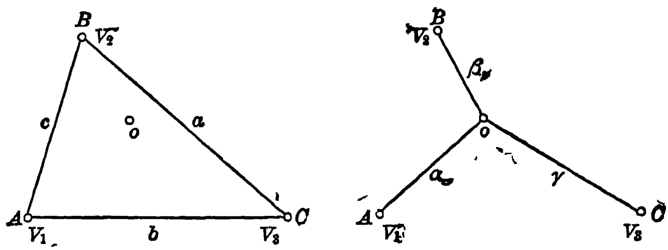


FIG 4.

. . . . by equivalent resistances, without disturbing the rest of the net-work, it is sufficient to have the resistances of the two parts of the net-work equal between each pair of knots, $A\ B$, $A\ C$, $B\ C$ . . . . In order to prove this, imagine only two potentials, $V_1\ V_2$ or $V_2\ V_3$ existing, and the others $V_3 = V_4 = O$ or $V_1 = V_4 = O$, find the partial current distribution of each pair and superpose them. For a triangle and three-pointed star, we obtain the following (Fig. 4). If the potential in C, $V_3 = O$, and the knots A and B have the potentials V_1 and V_2 respectively, the resistance c parallel

3. Herzog-Feldmann, "Berechnung der Leitungsnetze," 2. auflage I. Teil, p. 212. Published by Julius Springer, Berlin.

4. Dr. A. E. Kennelly "On the Determination of Current Strength in a Three-pointed Star Resistance System." *Elect. World and Eng.*, 1899, vol. 34, No. 8, p. 268; and "The Equivalence of Triangles and Three-pointed Stars in Conducting Net-works." *Elect. World and Eng.*, vol. 34, No. 12, p. 413.

to $(a+b)$ of the triangle must be equal to the resistance $(\alpha+\beta)$ of the star. This gives

$$\frac{1}{c}+\frac{1}{a+b}=\frac{1}{\alpha+\beta} \quad \text{or } \alpha+\beta=c\,\frac{a+b}{a+b+c} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

In the same way when the two transfigurations of resistances between A and C with the potentials V_1 and V_3 and with $V_2=O$ shall be equivalent, we must have

$$\alpha+\gamma=b\,\frac{c+a}{a+b+c} \ldots\ldots\ldots\ldots (2)$$

The difference of (1) and (2) gives

$$\beta-\gamma=a\,\frac{c-b}{a+b+c} \ldots\ldots\ldots\ldots (3)$$

But as between C and B, V_3 and V_2 for $V_1=O$

$$\beta+\gamma=a\,\frac{b+c}{a+b+c} \ldots\ldots\ldots\ldots (4)$$

we find by adding (3) and (4) $\beta=\dfrac{a\ c}{a+b+c}$ .... (III.)

Or in words, the resistance of each leg of the equivalent three-pointed star is equal to the product of the adjoining resistances of the triangle, divided by the resistance of its perimeter.

As a mnemotechnical rule[5] one may use the form

$$\alpha a=\beta b=\gamma c=\frac{abc}{a+b+c}\,.$$

The same will be found by a graphical investigation by taking

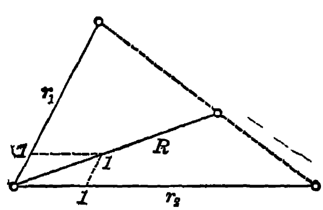


FIG. 5.

into consideration that for an angle (Fig. 5), the two resistances r_1 and r_2 of the legs connected in parallel give a resultant vector R whose unit is the resultant of the two units of the two legs. If the scales of the resistances of r_1 and r_2 are chosen equal, the result-

5. J. K. Sumec. *Zeitschr. für Electrotechn.*, Nov. 1, 1903.

ant resistance bisects the angle between r_1 and r_2. But in case the given resistances of the triangle a b c are such that drawn to the same scale they give a real triangle, i. e., are such that the sum of two sides is larger than the third, all the deductions given above may be read from Fig. 6 as follows:—

For the first step where the potential at $C=O$, c must be connected in parallel with $(a+b)$. To do this graphically we prolong A B by B C' equal to B $C=a$, bisect the angle at A and obtain point M, draw M H parallel to A C and obtain the required resulting resistance M H equal to A H. If we draw M N parallel to A B to the point of intersection N with B C, and N P parallel to A C, then N P must cut the bisector A M in the point O which is the center

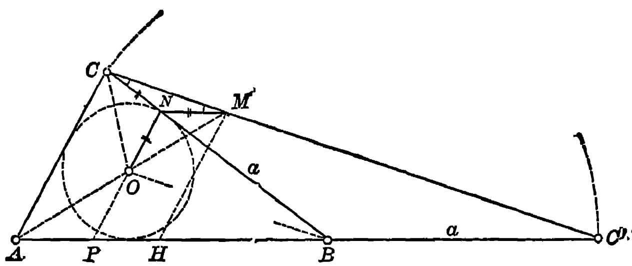


FIG. 6.

of the circle inscribed in the triangle A B C. According to the construction the angles N M O and N O M, also N M C and N C M must be equal. If we now draw C O, this line will bisect the angle at C. So we see that the parallels to the sides of the triangle drawn through the center of the inscribed circle determine the resistances of the legs of the three-pointed star. In order to transform a star connection into the equivalent triangle, we employ the formula

$$a' = \frac{\beta' \gamma'}{a' + \beta' + \gamma'}$$

where the *marked* values represent the conductivities of the resistances, or $a' = \frac{1}{a}$, $a' = \frac{1}{a}$, and so on.

3. Examples of the Method of Transfiguration.

I. Given the net-work represented in Fig. 7 with the feeding points I, II, III, of unequal voltage, and knots A B C D from which the currents I_1 I_2 I_3 I_0 are taken.

We discharge or relieve the knot D from its load I_0 by charging the adjoining knots A B C with the components

$$I_A = I_o \cdot \frac{0.00077}{0.002} = 0.385\, I_o;\ I_B = I_o \cdot \frac{0.00077}{0.0025} = 0.308\, I_o;$$

$$I_C = I_o \cdot \frac{0.00077}{0.0025} = 0.308\, I_o.$$

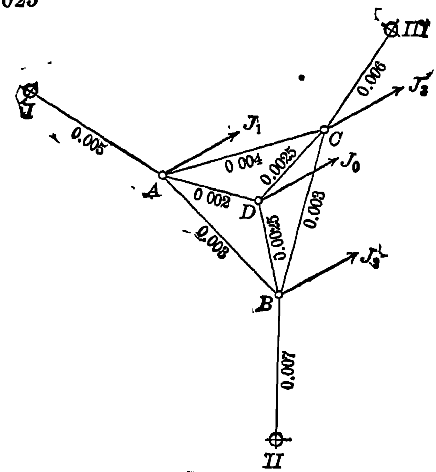


FIG. 7.

The numerator .00077 corresponds to the parallelism of the three resistances, A D=.002, B D=.0025, C D=.0025 ohms, and is,

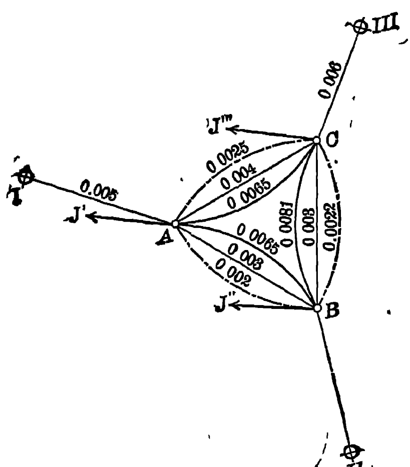


FIG. 8.

therefore, equal to $1 \div \left(\frac{1}{.002} + \frac{1}{.0025} + \frac{1}{.0025}\right) = .00077.$

The total currents which are now acting in the corners A B C, Fig. 8, may be denominated $I_1+I_A=I'$; $I_2+I_B=I''$; $I_3+I_C=I'''$. The star (.002, .0025,..0025) Fig. 7, is now replaced by the equivalent triangle (.0065, .0065, and .0081) shown in heavy lines in Fig. 8 by calculating its sides

$$.0065=\frac{\frac{1}{.002}+\frac{1}{.0025}+\frac{1}{.0025}}{\frac{1}{.002}+\frac{1}{.0025}}, \text{ \&c.}$$

We now have two parallel branches (.0065, .003), (.0081, .003), (.0065, .004) between each pair A B, B C, and A C of knots, and can replace them by their equivalents (.002, .0022, .0025) shown in Fig. 8 in dot and dash, which newly formed triangle may be trans-

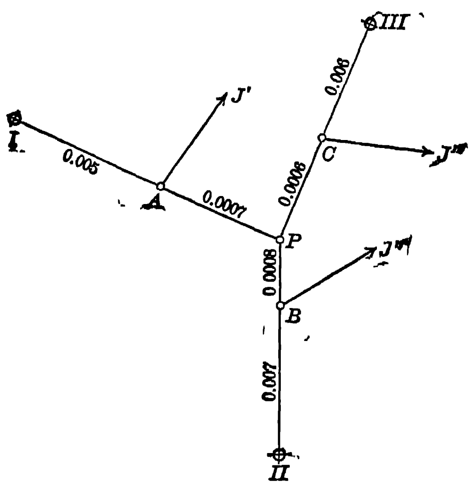


FIG. 9.

figured into the equivalent star shown in Fig. 9. If we now throw the load I' on knot I and P, the load I'' on knots II and P, and I''' on III and P, we obtain the following six components.

$$I_I'=I'\frac{.0007}{.005+.0007}=.123I'; \; I_P'=I'-.123I'=.877I'$$

$$I_{II}'=I''\frac{.0008}{.007+.0008}=.102I''; \; I_P''=I''-.102I''=.898I''$$

$$I_{III}'=I'''\frac{.0006}{.006+.0006}=.09I'''; \; I_P'''=I'''-.09I'''=.91I'''.$$

Hence I_P equals .877 I' plus .898 I'' plus .91 I'''.

If now the potentials at the feeding points *I, II, III* are equal, we may let them coincide and obtain as a resultant the connection in parallel of (.005+.0007); (.007+.0008); (.006+.0006) which resultant of the whole net-work is equivalent to .0022 and gives for the current flowing in the conductor I_P, II_P, III_P, respectively, the values

$$I_P \frac{.0022}{.0057} = .37 I_P;\ I_P \frac{.0022}{.0078} = .29 I_P;\ I_P \frac{.0022}{.0066} = .33 I_P.$$

Therefore, the currents flowing in the conductors I_A, II_B and III_C are

$$(.37 I_P + .123 I');\ (.29 I_P + .102 I'');\ (.33 I_P + .09 I'''),$$

and if now we substitute the values

$$I' = I_1 + .385 I_0;\ I'' = I_2 + .308 I_0;\ I''' = I_3 + .308 I_0$$

and

$$I_P = .877 I_1 + .898 I_2 + .910 I_3 + .893 I_0$$

we obtain as expression for the currents desired the following equations as *functions of the variable loads* $I_1\ I_2\ I_3\ I_0$

$$\begin{aligned} I_{IA} &= (.447 I_1 + .330 I_2 + .337 I_3 + .337 I_0) \\ I_{IIB} &= (.254 I_1 + .359 I_2 + .264 I_3 + .290 I_0) \\ I_{IIIC} &= (I_1 + I_2 + I_3 + I_0 - I_{IA} - I_{IIB}). \end{aligned}$$

Of course we could replace the calculation, taking all the phenomena at once by a superposition of four single actions for each of the currents, as may be seen from the linear form of the equations.[6]

Should the potentials of the feeding points *I, II, III* be unequal, it would be necessary to make another transfiguration of the star, Fig. 9, into a triangle. It may be pointed out that all questions as to the influence of variable loads caused by the extinguishing of lamps, the starting and stopping of motors, and the local displacement of the tapping point of a constant or variable load as caused for instance, by street-car motors, may be discussed completely, as the currents in the conductors are proved to be linear expressions of the load. If we go so far as to express the voltage of each knot as a function of the loads, we shall also obtain them as linear functions of the current consumed, as could be expected from the principle of superposition.

A net-work with four meshes and six knots is represented in *II*, Fig. 10. If we transfigure the triangle, *III V VI* into the equiva-

6. Herzog-Feldmann. *Electrotechn. Zeitschr.*, 1903, No. 9, p. 172.

lent star, *C III V VI*, we obtain the net-work shown in Fig. 11, which contains only three meshes. The resistances of the star are

$$III\ C = \frac{.02 + .03}{.01 + .02 + .03} = .01 \text{ ohms};$$

$$V\ C = \frac{.01 + .02}{.01 + .02 + .03} = .0033 \text{ ohms};$$

$$VI\ C = \frac{.01 + .03}{.01 + .02 + .03} = .005 \text{ ohms}.$$

If we now replace the consumer in *V*, taking 10 amperes, by the two component currents at the knots *C* and *IV*, we shall obtain for the first component

$$10.\frac{.02}{.02 + .0033} = 8.58 \text{ amperes}.$$

and for the second, 10—8.58 = 1.42 amperes.

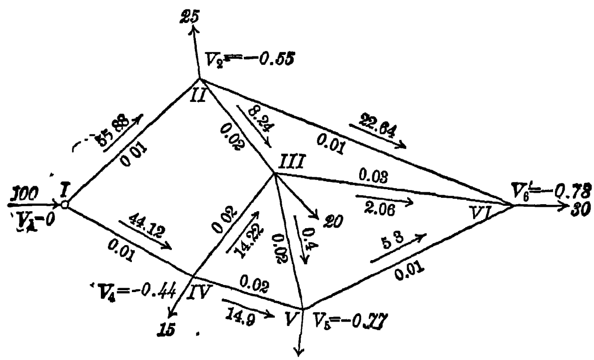


FIG. 10.

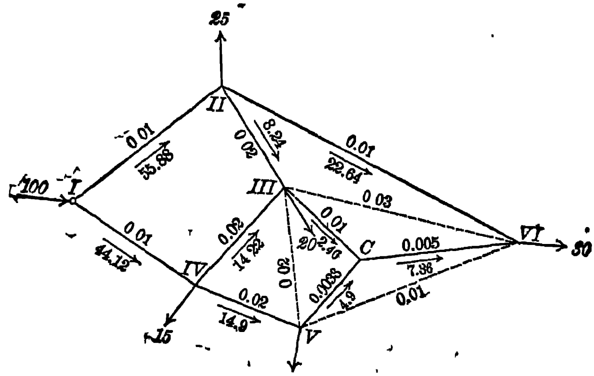


FIG. 11.

We shall, therefore, have a current of 15+1.42 = 16.42 amperes tapped from the knot IV. After having relieved knot V of its

load, we may regard *IV, V* and *V C* as connected in series so that the quadrilateral *III, IV, V C* takes the shape of a triangle, and

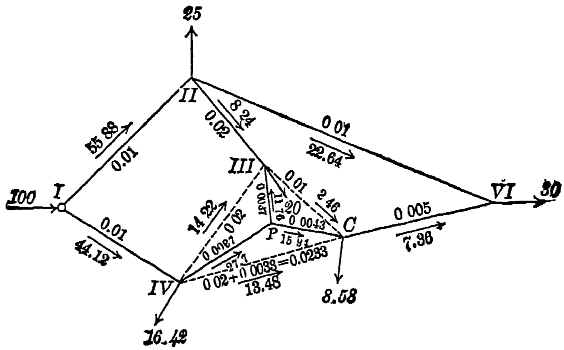


FIG. 12.

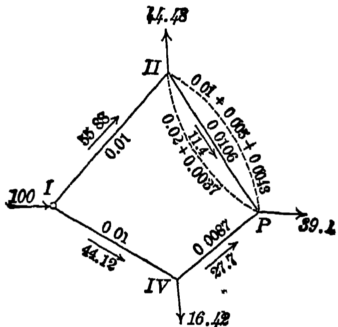


FIG. 13.

we can now replace the triangle *III, IV, C* (Fig. 12) by its equivalent star *P III; IV C,* whose legs have the resistances

$$III\,P = \frac{.01+.02}{.01+.02+.0233} = .0037 \text{ ohms}$$

$$IV\,P = \frac{.02+.0233}{.01+.02+.0233} = .0087 \text{ ohms}$$

$$C\,P = \frac{.01+.0233}{.01+.02+.0233} = .0043 \text{ ohms.}$$

After this step, the net only consists of two meshes. If we now carry the current at *III, VI,* and *C* to the knots *II* and *P,* we may connect the resistances *II, III* and *III P,* or *II, VI, VI C* and

C P in series, obtaining the two parallel branches shown in dotted lines in Fig. 13, and having a resultant resistance

$$\frac{(.02+.0037)\ (.01+.005+.0043)}{.02+.0037+.01+.005+.0043}=.0106 \text{ ohms.}$$

shown by the full line in Fig. 13. The currents at *II* and *P* may be calculated from

$$25+20.\frac{.0037}{.02+.0037}+30.\frac{.0043+.005}{.0043+.005+.01}+8.58\frac{.0043}{.0043+.005+.01}=$$

$25+3.12+14.45+1.91=44.48$ amperes,
and $0+(20-3.12)+(30-14.45)+(8.58-1.91)=39.1$ amperes respectively.

Now the whole net-work consists of but one mesh and we may find the currents in *I* and *II* and *I, IV* as the sum of the respective component currents. Therefore

$$I_{I\,II}=44.48\frac{.01+.0087+.0106}{.01+.0087+.0106+.01}+39.1\frac{.01+.0087}{.01+.0087+.0106+.01}$$

$$+\ 16.42\ \frac{.01}{.01+.0087+.0106+.01}=33.14+18.57+4.17-55.88 \text{ amp.}$$

and $I_{I\,IV}=(44.48-33.14)+(39.1-18.57)+(16.42-4.17)=$ 44.12 amp.

Instead of using this method we could have used others, which we developed years ago.

If we now assume a value for the potential at one of the knots, we will be able to find others. Take for instance $V_1=0$. Then the potential of V_2 and V_4 will be

$$V_2=-55.58\times.01=-0.55 \text{ volts}$$
$$V_4=-44.12\times.01=-0.44 \text{ volts.}$$

Having thus found the current and voltage distribution of the net-work in Fig. 13, we return to the net-work in Fig. 12. The resistance *II, P* was produced by paralleling two resistances, each of which takes an amount of the total current, 11.4 amperes, inversely proportional to its resistance. Therefore, the current in *II, VI, C P* will be

$$11.4\ \frac{.02+.0037}{(.02+.0037)+(.01+.005+.0043)}=6.28 \text{ amperes,}$$

and the current in *II, III, P* is equal to $11.4-6.28=5.12$ amperes. The current flowing in *II, VI* is the sum of this *conductor current* and the respective component currents that have been previously found, namely, $6.28+14.45+1.91=22.64$ amperes.

As only 30 amperes are tapped from *VI*, 30 — 22,64 = 7.36 amperes must arrive from *C*, and the current in the conductor *P C* must, therefore, be 8.58+7.36 = 15.94 amperes. The conductor current of *II III C* (Fig. 12) is 11.4—6.28 = 5.12 amperes, and, therefore, the current in *II, III* is the sum of this conductor current and that component, 3.12 amperes, of the current of 20 amperes which belongs to knot *II*, making the total current in *II, III* equal to 8.24 amperes. As 20 amperes are tapped at *II*, 11.76 amperes must arrive from *P* and 11.76+15.94 = 44.12—16.42 = 27.7 amperes must arrive at *P* from *IV*. The voltages at the knots *III* and *VI* may be found as follows:

$$V_3 = V_2 - 8.24 \times .02 = -0.55 - 0.16 = -0.71 \text{ volts}$$
$$V_6 = V_2 - 22.64 \times .01 = -0.55 - 0.23 = -0.78 \text{ volts.}$$

We have now found the current distribution in the star *P III, IV C* and can now determine the current distribution for the equivalent triangle *III, IV, C*, the current in *IV, III* being $(27.7 \times .0087 + 11.76 \times .0037) \div .02 = 14.22$ amperes.

The conductor *III C* will be passed by the current 14.22+8.24—20 = 2.46 and the conductor *IV, C* by the current 44.12—(14.22+16.42) = 13.48 amperes.

We have now found the current distribution of Fig. 12 completely and can return to the net-work in Fig. 11.

The current flowing in the conductor *IV, V* is the sum of the conductor current 13.48 and the respective component belonging to *II* 1.42 amperes of the 10 amperes which have been shifted from *V* on the adjoining knots. The voltage of knot *V* will be $V_5 = V_4 - 14.9 \times .02 = -0.44 - 0.3 = -0.77$ volts.

Having thus found the current and voltage distribution for the star, *C III; V, VI*, we try to find that of the equivalent triangle *III, V, VI*. The current in *V, VI* is $(4.9 \times .0033 + 7.36 \times .005) \div .01 = 5.3$ amperes. Hence the current in *III, VI* is 30—(22.64+5.3) = 2.06 amperes and finally the current in *III, V* is (10+5.3) —14.9 = (8.24+14.22)—2.06+20) = .4 amperes.

The current and voltage distribution which we have found in this way has been added to Fig. 10. It has been found without solving any equation and exclusively by applying the method of transformation. The manner in which we proceeded was a recurrent one; we first simplified the complicated case by steps and finally returned to the original case.

4. TRANSFIGURATION OF QUADRILATERALS.

We have so far taken only ohmic resistances into consideration. But the conclusions obtained and the manner of obtaining them remain unaltered for inductive resistances, if we regard them as directed or complex quantities, and interpret the operation of adding, substracting, etc., in this enlarged sense. So for instance, the law of superposition will be unaltered if we understand the superposition in the same way as it is understood for two forces in mechanics. It is to the credit of Mr. Charles P. Steinmetz of having opened this new field in practical electrotechnics.

According to the preceding, the laws of transfiguration are applicable even to negative resistances (for instance, a counter e.m.f. divided by the current), as may be seen from Fig. 5, where the bisector would bisect the supplementary angle between r_1 and r_2.

Having stated this we may proceed to transfigure the simple quadrilateral by adding a diagonal which brings this case back to

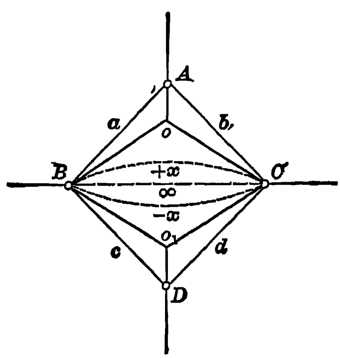


FIG. 14.

the transfiguration of triangles. Fig. 14 represents a quadrilateral with the voltages $A\ B\ C\ D$ and the resistances $a\ b\ c\ d$. The additional diagonal $B\ C$ of infinite resistance may be replaced by two parallel resistances of $+x$ and $-x$ as

$$\frac{1}{\infty} = \frac{1}{x} + \frac{1}{(-x)}.$$

We have now split the quadrilateral into the two triangles $a\ b\ (+x)$ and $c\ d\ (-x)$ which we can transfigure into the stars $O\ A\ B\ C$ and $O_1\ B\ C\ D$ shown in heavy lines in Fig. 14. The volt-

ages of O and O_1 are, however, functions of the resistance and may be expressed by

$$O = \frac{A\,x + B\,b + C\,a}{x + b + a} \text{ and } O_1 = \frac{D\,(-x) + B\,d + C\,c}{(-x) + d + c}.$$

If we were now allowed to assume the voltages at O and O_1 as equal, those points would coincide and we would obtain the desired star. But at the same time we should find a *certain* value of x as a function of the potentials at the corners, which is not permissible in the assumed general case of *unlimited transfiguration.* This general transfiguration is, therefore, impossible.

5. Method of Splitting the Net-works.

In most of the practical cases the net-works may be split up into such parts or sections as by themselves can be completely treated by the method of transfiguration. But in order to obtain the final current or voltage distribution of the whole net-work a special research for the *inter-connection* of the sections is required.

A special example may serve as an introduction into this new

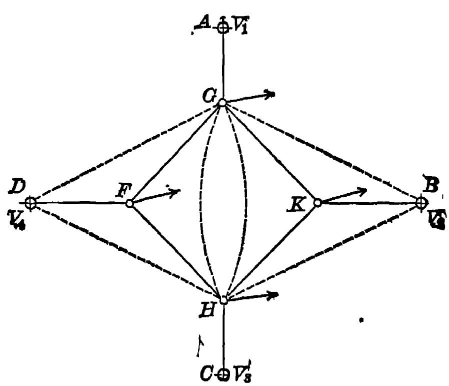


Fig. 15.

trend of thought. Fig. 15 represents a quadrilateral $G\ K\ H\ F$ whose corners are fed from four points, $A\ B\ C\ D$, with the voltages $V_1\ V_2\ V_3\ V_4$. If now we shift the loads from the knots $G\ H$ and transfigure the stars around F and K into the equivalent triangles as shown by the dotted lines in Fig. 15, we obtain the net-work in Fig. 16, which can be treated easily by cutting the connecting con-

ductor ρ_x between *G* and *H*, and by adding an unknown *substitutional current* (Ersatzstrom), $+I$ and $-I_x$ for each of the stars *F* and *K*. The voltages at *G* and *H* are

$$V_x^{I} = a_I + b_I I_x \text{ and } V_x^{II} = a_{II} - b_{II} I_x ,$$

Their difference is, therefore,

$$(a_I - a_{II}) + (b_I + b_{II}) I_x = I_x \cdot \rho_x ,$$

from which it is easy to calculate the unknown current I_x. In the same manner of reasoning, more complicated cases can be treated.

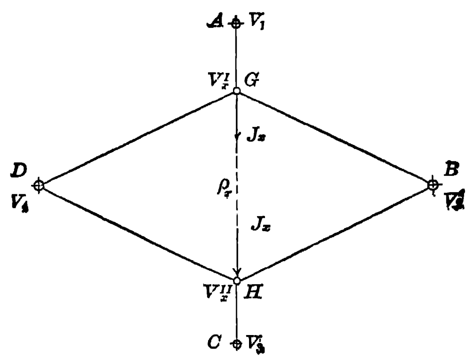


FIG. 16.

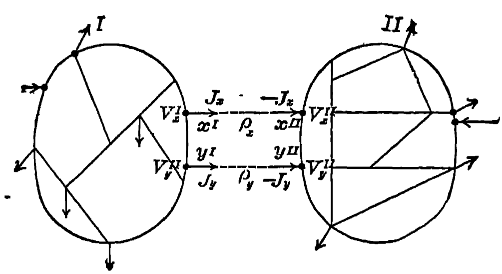


FIG. 17.

Fig, 17 represents a net-work consisting of the sections *I* and *II* inter-connected by two conductors with resistances ρ_x and ρ_y. If we cut these conductors, we must take as substitution for section *I*, the currents I_x and I_y, and for section *II*, the currents $-I_x$ and I_y. As the voltages at the knots are linear functions of these

loads at the knots, we may represent the voltages in the four interconnecting knots by

$$\left.\begin{aligned} V_x^{I} &= A_1^{I}\, I_x + B_1\, I_y + C_1^{I} \\ V_y^{I} &= B_2^{I} I_x + A_2^{I}\, I_y + C_2^{I} \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots I$$

$$\left.\begin{aligned} V_x^{II} &= A_1^{II}(-I_x) + B_1^{II}(-I_y) + C_1^{II} \\ V_y^{II} &= B_2^{II}(-I_x) + A_2^{II}(-I_y) + C_2^{II} \end{aligned}\right\} \ldots\ldots II.$$

where the constants A, B, C are functions of the resistances of the net-work. For instance, A_1 would be numerically equal to the voltage in knot X^1, if all other knots in section I including Y^1 were unloaded and I_x were equal to unity. So in the same way B^1 would be the voltage in the knot Y^1, if unit current were taken from there, all other knots being unloaded. From equations I and II there follows

$$\begin{aligned} I_x\, \rho_x &= (A_1^{I} + A_1^{II})\, I_x + (B_1 + B_1^{II})\, I_y + (C_1^{I} - C_1^{II}) \\ I_y\, \rho_y &= (B_2^{I} + B_2^{II})\, I_x + (A_2^{I} + A_2^{II})\, I_y + (C_2^{I} - C_2^{II}) \end{aligned}$$

$$\left.\begin{aligned} (\rho_x - A_1^{x} - A_1^{II}) I_x - (B_1^{I} + B_1^{II})\, I_y &= C_1^{I} - C_1^{II} \\ -(B_1^{I} + B_2^{II}) I_x + (\rho_x - A_2^{I} - A_2^{II})\, I_y &= C_2^{I} - C_2^{II} \end{aligned}\right\} \ldots\ldots M$$

and from the main linear equations M we may calculate I_x and I_y the coefficients being symmetrical to the diagonal. If there are more than two connections, the number of equations rises correspondingly. If some of these resistances are zero, this means that the sections are connected directly by these knots, or to put it more clearly, the splitting of the net-work in sections has been carried out by splitting multiple-knots. This new method even remains unaltered in its essential parts if instead of simple connectors, whole parts of net-works or sections are interspersed.

There are two opposite ways of explaining the constitution of a net-work. The first starts with the knots and regards the conductors only as connectors of the knots, which are either *feeding points* and thus provided with known potential, or are *free knots* on which the potential is impressed by the current circulating. The second starts with the assumption of individual meshes in which currents circulate. By joining these meshes, the knots with their potentials are formed. To these two ways of constituting a net-work, correspond the analytical methods of finding the current or the potential distribution. The first method seeks to find immediately the current in the conductors; the second, the voltage in the knots.[7] The solution of the linear equations thereby obtained

7. Herzog-Feldmann. "Die Berechnung Elektrischer Leitungsnetze," II. Auflage, p. 162.

leads to determinants, and as far back as 1847 Kirchhoff tried to simplify it.[8] Lately Prof. Feussner[9] has continued this work with success, and others have followed him. Our method of transfiguration here evolved corresponds to a physical way of eliminating unknowns from incomplete linear equations. If we transfigure a triangle into a star, we open a mesh; if we transform a star into a triangle, we eliminate a knot and, therefore, its unknown voltage. Thus the method of transfiguration corresponds to both the methods of finding either the current distribution or the voltage distribution. On account of its simplicity, the transfiguration will certainly be employed to simplify given net-works in order to find their current and voltage distribution. As practical net-works will always contain only an incomplete net-work of connectors between their knots, the transfiguration together with the novel principle of splitting up net-works will in many cases be sufficient for a complete solution of the problem in question. We, therefore, hope that the method of transfiguration which we have explained here in a synthetical way, and which has been created by an ingenious theorem of Kennelly, will find recognition and further adherents in practice.

Discussion.

Chairman Lieb: This paper recalls some early work. At the time the network supplied by the historic Edison station in Pearl street was projected, a model was made to scale of the district which it was proposed to cover. A distribution to customers was represented by resistance spools which were located on the map corresponding to the customers' locations, the winding of the spools corresponding to the connected installation. A careful study was made by Prof. Claudius of this model in 1881, to locate the proper points at which feeders should be connected to maintain a uniform distribution of potential. The feeders were all laid in accordance with this experimental determination, but as they were two-wire feeders they have long since been replaced. In electricity supply undertakings, in which the area covered by the low-tension supply mains is not too large, and where the demands for service are rapidly increasing, it is becoming the practice to install two or three sizes of mains, and use these sizes throughout — the heavier mains in the heavily loaded districts, and the small sizes in the residential districts. One or at most two sizes of feeder are adopted, and feeders are added to the district at the proper feeding point to secure uniform distribution of potential as the business grows. In other words, instead of making a careful theoretical or experimental determination of the supply area, it becomes a question of the invest-

8. Kirchhoff, *Poggendorffs Annalen*, 72, 1847.
9. W. Feussner, "Ueber Stromverzweigungen in Netzförmigen Leitern," *Annalen der Physik*, 1902, No. 13.

ment which the undertaking can stand in anticipation of the growth of the demand, with the addition of new feeding points as the load increases.

Col. R. E. B. CROMPTON: I can strongly corroborate your Chairman's remarks. In the year 1882 when Mr. Gisbert Kapp and myself were designing the first underground network in one of the southern districts of London we made just such a working scale model of the district, but we found that the question of who would first take the supply in the very early days of the industry was such an uncertain factor that our model was of practically no use. Although I do not undervalue the work put into this paper by the authors, I doubt very much if it has any practical value in the calculation of the network of large cities. We find it most convenient to put down a substantial network in the first place and provide for increased density of demand by adding to the number of feeders as the demand increases. Alterations in the network are very troublesome after consumers are once connected to it, whereas feeders can be added without any such interference.

DR. A. E. KENNELLY: The paper before us is a valuable contribution to electrotechnical literature, in the direction of simplifying the work of computing conducting networks. It is true that in the practical layout of distributing mains and feeders, it is not worth while attempting to compute the distribution. The load conditions change so rapidly in any given district that a computation for one year would become useless the next. Nevertheless the problem of computing the current distribution in a network without excessive labor is an important one; because occasionally the commercial need of it will arise, and moreover, as part of the complete machinery of electric power distribution, the engineer should be in possession of means for checking and comparing practice with theory.

The key to the treatment of the subject by the authors is the separation of the load currents from the no-load currents. They first consider the currents that would flow through any knot of the system by reason of differences in the pressure at the feeding points, and with all loads assumed removed. Then they superpose upon this no-load current system the currents flowing from the feeding points to the branches of the knot for the supply of the loads, and with the pressure at feeding points assumed uniform.

It may be merely a matter of opinion; but the formulæ seem to be simplified if conductances are substituted for resistances of the conductors. Thus the formula on page (691) becomes

$$I_1 = I\frac{c_1}{C} + V_1 c_1 - \frac{c_1}{C}(\Sigma V_n c_n) \qquad \text{amperes.}$$

Where $c_n = \frac{1}{r_n}$ is the conductance of a conductor in mhos, and C is the sum of the conductances meeting at the knot-point. The first right-hand term expresses the load current, and the two remaining right-hand terms together express the no-load current through the feeding point No. 1.

Another point of great interest in the paper is the virtual solution of a mathematical problem by a physical substitution. There are a number of

such instances known; as, for example, the solution of a purely mathematical problem — a moment of inertia, by determining the period of oscillation of a uniformly dense body possessing a definite corresponding form. The experimental solution of the mechanical problem determines the result corresponding to the solution of the mathematical problem. In the case referred to in the paper under the title "Transformation of quadrilaterals," it is shown that the solution of a certain system of simultaneous equations can be greatly simplified by substituting stars for triangles, or *vice-versa.* This leads to a method having great simplicity and power.

The authors are to be congratulated upon the success of the methods they employ in dealing with the computation of networks from an engineering standpoint.

Mr. PETER JUNKERSFELD: I do not know that anything I could add would be of interest, as I agree with what Col. Crompton and others have said as to the calculation of networks. In Chicago it is largely a question of investment and anticipating future demand, and of putting down two standard sizes of mains. As the business grows and mains become overloaded, additional feeding points are inserted to increase the network — and as the feeders become overloaded and we eventually need more feeder capacity than can be handled economically we install additional sub-stations. The thing to keep in mind is to add feeders to strengthen the mains, and to add sub-stations to strengthen the feeders.

CHAIRMAN LIEB: We will now consider the discussion closed. We will call on Dr. Steinmetz to read his paper on "The Electric Arc."

THE ELECTRIC ARC.

BY CHARLES PROTEUS STEINMETZ.

I.

While the electric arc represents one of the most important applications of electric power, relatively little theoretical research has been made of this phenomenon from an engineering point of view, but the work of the last years has either been of a more physical or rather metaphysical nature: on the electric discharges in gases, the electron theory, etc., or restricted to the carbon arc. Though the carbon arc constitutes by far the most important application, the carbon arc is not a typical electric arc, but carbon takes an exceptional position, acting as arc electrode different from almost all other substances. For instance, carbon is the only, or at least one of the very few substances which can maintain a steady alternating arc at relatively low voltage. This is probably one of the reasons why carbon has been used exclusively as arc electrode.

A typical arc, that is, an arc representing the character of the arc discharge between by far the largest majority of substances, is, for instance, the arc between iron and copper, or between their conducting oxides, and a typical vacuum arc is the mercury arc.

In the following I intend therefore to give a short review of the results of investigations on the phenomena of the electric arc made during the last years in the electrochemical research laboratory of the General Electric Company, for which work I am largely indebted to Dr. Whitney and Dr. Weintraub. A more complete publication of the records of these investigations must be postponed for a later occasion.

II.

If two conductors in contact with each other are included in an electric circuit traversed by a direct current, and these conductors gradually withdrawn from each other, the current continues to pass through the gap between the conductors as a luminous discharge. In this case the current does not pass through the medium surrounding the conductors, by a disruption of this medium, as is the case

with the electrostatic spark, but the current is carried across the gap by a bridge of conducting vapors of the electrodes, established and maintained between the electrodes, and an interruption of this vapor stream stops the flow of the current.

At the ends of the two electrodes or terminals heat is produced, especially at the positive terminal. The arc stream has an appearance very similar to a blast flame issuing from a point or small space of the negative terminal or cathode towards the positive terminal or anode, and surrounding the latter in a diffused glow. The arc consists of a relatively narrow inner core, frequently of intense brilliancy, which seems to be the real path of the current, and a mantle or shell surrounding the core, of lesser intensity and duller color, and of a thickness increasing towards the anode, like a penumbra. Where the cathode is liquid, as in the mercury arc, or sufficiently fusible so that a liquid pool forms on it, the negative point runs around on the surface of this pool with great rapidity and in an erratic manner. If, however, pieces of solid conducting material, wetted by the cathode material, float on the cathode pool, the negative point centers on one of these projections, becomes stationary and the arc steady.

III.

In general, the spectrum of the arc is that of the cathode material, and the material of the anode does not affect the arc stream. Changing the anode does not change the character and appearance of the arc stream, but with a change of the cathode the spectrum and so the whole character of the arc flame changes. For instance, with magnetite ($Fe_3\,O_4$) and copper electrodes, by making the magnetite negative or cathode, the arc flame is of intense brilliancy and whiteness, showing the iron spectrum; but making the copper cathode, the arc changes to the green and less brilliant copper arc, although now the magnetite becomes very much hotter than when used as negative, and rapidly melts down. The spectrum of the anode material appears in the arc flame only if the anode is more volatile than the cathode, and the size of the anode is so small that its surface is heated by the surrounding arc flame to a high temperature, but it disappears by cooling the anode, as by making it of sufficiently large size and high heat conductivity. The cathode spectrum of the arc stream, however, does not disappear by cooling the cathode. Where the anode is composite, containing some more volatile material, only the spectrum of the volatile constituent may appear.

Where the anode material appears in the arc flame, it first shows at the surface of the anode, gradually spreading from there with increasing anode temperature, but generally does not stream towards the cathode, as the cathode flame does toward the anode, but is deflected sidewise by the blast from the cathode. This is especially marked when a drop of material of lower heat conductivity, as magnetite, sticks to an anode of high heat conductivity, as copper. This drop of magnetite then gets very much hotter and the arc centers on it. This results in the appearance of a "positive blast" similar to the negative blast or the arc flame, but differing essentially from it in that it curves away from the cathode and its base is fixed, while the "cathode blast" points toward the anode and its base usually is in rapid motion.

It therefore seems that the vapor bridge, which carries the current from electrode to electrode, is supplied exclusively from the cathode, that the cathode material is carried into the arc flame by the electric current, but that the anode material enters the arc flame only indirectly by evaporation, if the anode is sufficiently hot.

If the anode is kept sufficiently cool no consumption whatever of the anode takes place, but the cathode material condenses on the surface of the anode. By reducing the size of the anode, but so that its temperature is still below that where evaporation takes place, the condensation of the cathode material on the anode can be stopped, and in this case the anode (if it consists of a material, as silver, which is not attacked by the air while red hot) does not change at all.

The cathode, however, always consumes, at a greater or less degree, in feeding the arc flame. The amount of material evaporated from the cathode is as a rule very many times greater than the amount of vapor required to carry the current. It can, by restricting evaporation from the cathode, by cooling or other means, be reduced to a very small fraction of its former value, without corresponding decrease of the brilliancy and so luminous efficiency of the arc flame, or considerable change of the voltage consumed by the arc, so that it seems that by far the greater amount of vapor produced by the current from the cathode does not participate in the conduction of the current. Only by extreme restriction of evaporation from the cathode, a decrease of the brilliancy of the arc flame is produced, but even then the voltage consumed by the arc does not noticeably change, or only slightly rises.

The amount of material carried by the current from the cathode is extremely small compared with the amount of material which the same current would carry through an electrolyte by Faraday's law.

The arc stream issues from the negative point on the cathode as a high-velocity blast, apparently of very high velocity-energy, as can best be observed on the mercury arc in vacuo. In the mercury arc, at a vacuum so low that the mercury gauge does not show it any more (estimated as of a magnitude of 1/100,000 atmosphere), solid pieces of considerable size, as pieces of glass of a couple of millimeters diameter, when caught by the cathode blast, are thrown upward and kept in suspension, dancing on the arc blast.

In arcs in which the cathode is liquid or sufficiently fusible to form a liquid pool, the negative spot rapidly runs over the liquid surface and presses itself into the surface, that is, the arc starts from the bottom of a depression, which in the mercury arc is one-eighth inch or more deep. This depression appears to me the necessary counterpart of the negative blast, that is, the recoil of the negative blast. Since, however, the arc tends to go from the highest point of the cathode, it climbs up the sides of the depression, but in doing so depresses its base again and so shifts the depression. This appears to me the cause of the rapid motion of the cathode point. By focusing the negative point on a solid projecting above the pool, the tendency of the arc to move away from its depressed base is converted into a tendency to remain stationary at the projection as highest point of the cathode.

IV.

To produce the negative blast which carries the current in the arc flame, power is required, which is consumed in evaporating the cathode material, as the mercury in the mercury arc, and gives the vapors their high rectilinear velocity. This power finds its equivalent in a potential drop at the surface of the negative terminal, or a cathode drop of voltage. The heat produced at the anode is greater than that due to conduction from the arc stream and due to the arrest of the rectilinear motion of the arc blast, since the anode may reach far higher temperatures than the arc stream (in the mercury arc, for instance, the graphite anode may become white hot, while the arc stream temperature is far below incandescence, as shown by a carbon filament inserted in the axis of the arc stream not becoming luminous), and by gradually reducing the arc blast

by means of cooling the cathode and arc stream, the temperature of the anode is usually not decreased. The heat of the anode is approximately proportional to the current and the energy converted into heat finds its equivalent in a difference of potential at the anode surface, or anode drop of voltage.

Plotting the voltage consumed by mercury arcs (with two mercury terminals) of different lengths, but of the same current and the same diameter, as function of the arc length, gives straight lines pointing toward 13 volts at zero arc length, irrespective of diameter and current strength, at least within wide limits. In the mercury arc the voltage consumed at the terminals therefore seems to be constant, the voltage consumed by the resistance of the arc stream being proportional to its length.

In the magnetite arc the voltages as function of arc lengths for constant current are curves which are nearly straight lines and point toward a value of about 30 volts. Direct observation by bringing the terminals slowly together and noting the voltage immediately before it drops suddenly, or separating the terminals and reading the voltage immediately after it has suddenly risen, also lead to values between 28 and 31 volts, so that with the magnetite arc the sum of the potential drops at the terminals is about 30 volts and seems to be independent of the current and arc length. It does not change much with a change of the anode, as is to be expected. The voltage consumed by the resistance of the arc stream in the magnetite arc and other arcs at atmospheric pressure is only approximately proportional to the arc length.

In the carbon arc the phenomenon seems to be more complicated and the curves of the arc voltage at constant current and varying arc length differ from straight lines considerably, especially for very short arc lengths, so that the potential drop of the terminals can not well be estimated from them.

If at constant arc length the current is gradually lowered, at a certain value of current the arc suddenly goes out, irrespective of the voltage of the supply circuit (providing this voltage is not of a magnitude sufficient to send an electrostatic spark across the gap between the terminals). This phenomenon appears more or less marked in all arcs, but especially so with the mercury arc in vacuo. For instance, in a mercury arc of seven-eighths inch diameter and 16 inches length, shown in Fig. 1, of which the voltampere characteristic is shown in Fig. 2, the arc is stable at 2.4 amperes on a 50-volt circuit, but immediately below this cur-

rent goes out after a few minutes even on a 250-volt circuit. If, however, from the same cathode C an arc of one ampere

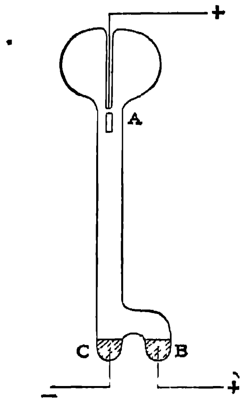


FIG. 1.—MERCURY ARC TUBE, WITH AUXILIARY ANODE.

is run to an auxiliary anode B, then the current in the main arc CA can be lowered to 1.4 amperes without either the main arc

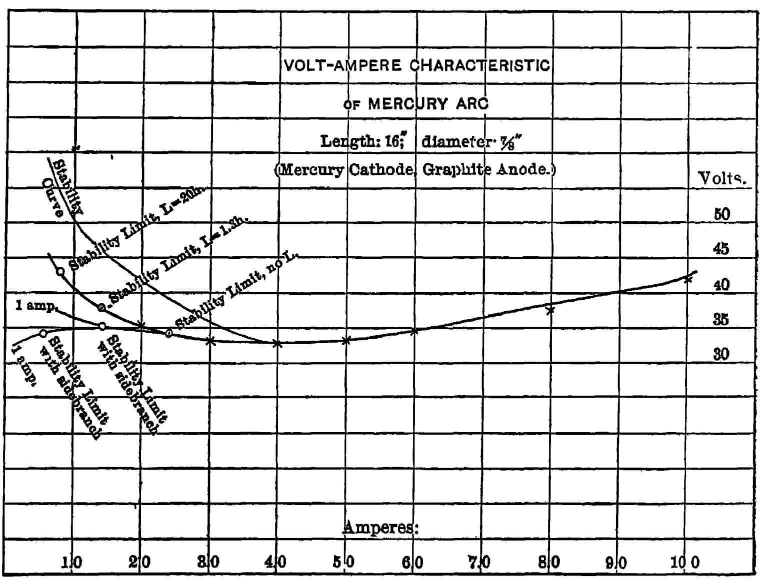


FIG. 2.

or the auxiliary arc going out. Below 1.4 amperes the main arc goes out and without the main arc the auxiliary arc CB goes out

after a short time. By raising the auxiliary arc *CB* to 2 amperes, the main arc can be lowered to .4 amperes before it fades out. In either of these cases the arc *CA* becomes unstable, if the total current issuing from the negative point falls below 2.4 amperes. If, however, a number of pieces of conducting material wetted by the mercury, as iron or chromium, float on the mercury, then the negative point of the arc focuses on one of these pieces and the arc becomes stable down to a fraction of an ampere, but goes out below 2.4 amperes if the negative point leaves the iron and begins to run over the mercury surface. By the insertion of 1.3 h inductance the stability can be carried down, without focusing the negative point, to 1.3 amperes; with 20 h inductance down to .8 amperes.

Herefrom it appears that the stability of the arc does not depend upon the arc stream and the anode but entirely on the cathode The power required to produce the negative blast, which carries the current, can be assumed as proportional to the current. This power is given by the electric power expended in the potential drop at the cathode surface. The rest of this electric power is either conducted away as heat or used in producing a surplus of mercury vapors over that required to carry the current. The power conducted away by the cathode as heat is quite considerable where the negative point rapidly moves over the cathode surface and so continuously strikes fresh mercury, and varies with the rapidity of the motion of the negative point. With decreasing current its percentage rapidly increases, since the available energy decreases proportionally to the current, while the heat conductance at the cathode spot decreases much slower. Hence at a certain current this percentage becomes so large that not enough energy is left to produce the negative blast and the arc extinguishes. Since the amount of energy carried away by heat conductance increases with the velocity of motion of the negative spot, not much below the limit of stability the arc may run for several minutes before it is extinguished by some unusually rapid motion of the negative spot. This explains that only the current issuing from the cathode is essential for stability, but it is immaterial whether this current goes to one or several anodes. By fixing the negative point, the energy consumed in continuously heating new mercury surfaces is saved and the limit of stability therefore extended further downward. The reactive coil, by storing energy as magnetism and returning it when the arc tends to go out, supplies the energy required at the cathode point at a moment of rapid motion and so extends

the stability more or less. This unstability at low currents discussed here has no relation to the unstability of any arc on constant potential due to its volt-ampere characteristic, which will be discussed later.

V.

If with one cathode *C* two anodes *A* and *B* are used within reach of the same arc flame, as for instance with a mercury arc in the

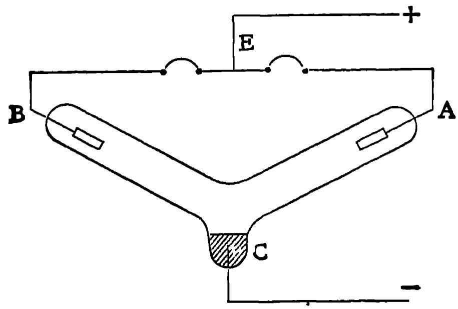


FIG. 3.—DOUBLE-ANODE MERCURY ARC TUBE.

same vacuum tube, as shown in Fig. 3, the arc can be shifted from anode to anode. If after closing the circuit *EA* and establishing the arc *AC* the circuit *EB* is closed and then the circuit *EA* opened, the arc is shifted from *AC* to *BC*. During the time when both circuits *EA* and *EB* are closed, both arcs *CA* and *CB* flow and the

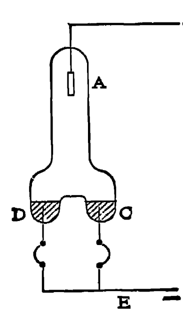


FIG. 4.—DOUBLE-CATHODE MERCURY ARC TUBE.

current divides between *EA* and *EB* proportional to the resistances of the two circuits *EAC* and *EBC*, and the potential drops at *A* and *B*, which latter depend upon the material, size and temperature of the anodes *A* and *B*.

If, however, with one anode *A*, two cathodes *C* and *D* are used, as in Fig. 4, and after closing the circuit *EC* and establishing the

arc *CA*, the circuit *ED* is closed, the current still flows over the cathode *C* and no current flows in *ED*, and if *EC* is opened the arc goes out.

With two separate anodes (Fig. 5) and considerable resistance in the circuits of these anodes, it is possible, though difficult, to operate two cathodes, but both circuits have to be started separately by bringing their terminals into contact, and one arc *AC* does not start the other arc *BD*, but if after starting arc *AC* the circuit *ED* is closed, an arc starts at *B*, but goes over the surface of *D* to the common cathode *C*, and all the current returns over *C*, even if considerable resistance is inserted in series with *C* and *D* separately, and it is difficult to shift the arc from *C* to *D*.

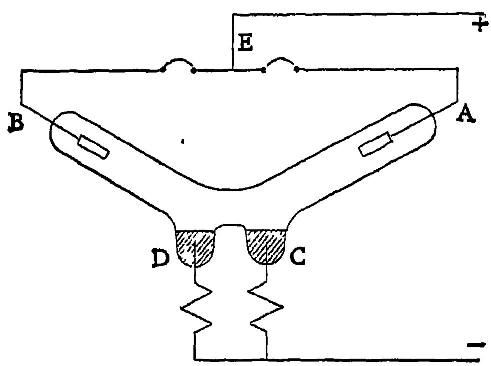


FIG. 5 — DOUBLE-MERCURY ARC TUBE.

The conclusion from the impossibility of shifting the arc from cathode to cathode and the ease of shifting it from anode to anode, seems to me that the arc must be continuous at the cathode. The explanation hereof seems simple: Since the arc blast, which carries the current between the electrodes, issues from the cathode, any interruption of the arc blast at the cathode breaks the circuit, while an interruption at any other place of the arc stream is closed by the arc blast on the cathode side of the break.

These phenomena, while characteristic of all typical arcs, are easiest studied on the mercury arc, due to its great length, relatively low surface intensity, sharp definition of the space which can be reached by the arc vapors, the inside of the arc tube, and the absence of red rays, which permits close inspection even of very intense arcs through a red glass.

VI.

Between two magnetite terminals, with a direct current of 4 amperes, an impressed e.m.f. of 100 volts can maintain a steady arc of five-eighths inch length. If, however, an alternating e.m.f. even as high as 250 volts is impressed upon a circuit of such resistance as to permit 4 amperes to flow, and two magnetite terminals in contact with each other are included in the circuit, when attempting to start an alternating arc by withdrawing the magnetite terminals from each other, the circuit opens even with a very minute gap, less than one thirty-second inch. That is, 250 volts 4 amperes cannot maintain even a very short alternating arc between magnetite terminals, or, in other words, magnetite may be called "non-arcing" for alternating current, and at least 500 volts are required to maintain an alternating arc, and then the arc is unsteady, noisy, and a direct-current ammeter in the circuit shows a unidirectional current, that is, at least partial rectification.

With the mercury arc the difference is still more marked: 25 volts direct current will maintain an arc of several inches length when once established. To maintain an arc of the same length, an alternating e.m.f. of several thousand volts is required, so high that it strikes across the gap between the electrodes and establishes itself, at least after preheating the arc tube to the temperature which it has while the arc is running. At lower alternating voltage the arc immediately extinguishes. If by a sufficiently high alternating voltage an arc is struck, the current passing is entirely unidirectional, that is, only every second half wave passes, and a still much higher voltage is required to hold a true alternating arc, in which both half waves pass.

The explanation of this phenomenon seems to me found in the required continuity of the arc blast at the cathode; withdrawing the terminals from each other, with an alternating e.m.f. in the circuit, the current passes during one half wave. For the next half wave, however, the other terminal should be cathode and the arc so goes out, since no cathode blast issues from the other terminal. If the voltage is sufficiently high, it strikes across the gap between the electrodes and establishes an arc. The next half wave, however, has to stop the vapor stream of the preceding half wave and to produce a reverse vapor stream, and this requires a higher voltage than merely to establish the vapor stream; hence, if the voltage is not very much higher than the striking voltage, the second half wave does not pass. The third half wave is again in

the direction of the first, thus strikes across, now easier by using the remnant of the vapor stream of the first half wave; the fourth half wave again cannot pass, etc. In this manner rectification of the arc with an alternating e.m.f. appears as the natural result of the negative blast. There exists then with any such arc a range of voltage between that required to strike across the terminals and establish the arc and that required to reverse an existing arc, where rectification takes place.

If by an auxiliary terminal *B*, Fig. 1, a direct current arc is maintained between one terminal *C*, and *B*, then an alternating e.m.f. of the same magnitude as that required for the direct-current arc establishes and maintains an arc between terminal *A* and that terminal of the direct-current arc *BC* which is cathode. But this arc is unidirectional, its cathode being the cathode of the direct-current arc. Here then the continuity of the cathode blast is maintained by the direct-current arc. Obviously, the same result can be produced by overlapping several arcs with common cathode so that before one arc ceases at zero e.m.f. another e.m.f. starts another arc with the same cathode, and so a continuous cathode blast is produced. Or the two successive half waves of e.m.f. can be utilized by extending by means of inductance the current of each half wave beyond the zero e.m.f., until the arc of the next half wave has started.

We have then, with an alternating e.m.f.,

1). A range of voltage from zero to the voltage required by a direct-current arc of the same length, where nothing takes place.

2). A range of voltage from the direct-current arc voltage, say 25 volts in the mercury arc, to the striking voltage between the electrodes, say 6000 volts, where a unidirectional or rectifying arc takes place, if the cathode blast is maintained by what may be called separate excitation.

3). A range of voltage, between the striking voltage and the voltage required to reverse a cathode blast of opposite direction, say between 6000 and 9000 volts, where a unidirectional or rectifying arc occurs without a separate excitation.

4). A range beyond the latter voltage, say 9000 volts, where a true alternating arc passes.

This phenomenon leads to the arc rectifier, which now is becoming of practical importance.

Most arcs show more or less complete rectification within a certain range of voltage and so do not operate well on alternating cur-

rent, except the carbon arc, which shows a very incomplete rectification only where a great dissymmetry of electrodes exists. The range within which rectification occurs, however, varies greatly. It is the range between the direct-current arc voltage and the electrostatic striking voltage between the electrodes at arc temperature. With increasing arc temperature, that is, change of material of the cathode, at constant arc length and current, the arc voltage increases. The voltage required to strike across the gap through the hot vapor stream decreases with increasing temperature of the vapor stream. Therefore the voltage range of rectification is enormous with the very low temperature mercury arc. With the very much higher temperature of the magnetite arc it is already fairly narrow, about between 100 volts and 500 volts, and it may well be that with the still much higher temperature of the carbon arc, which is the hottest arc, the striking voltage falls below the arc voltage, and that this is the reason that the carbon arc does not rectify, but runs steadily on alternating current. Some very refractory substances, as calcium carbide, also show no marked rectification, and in arcs like the magnetite arc, rectification can more or less completely be suppressed by greatly increasing the temperature of the arc stream.[1]

VII.

At constant current, the voltage consumed by an arc increases with increase of arc length. At constant arc length, the voltage of the arc decreases with increase of current. Merely considered as electric conductor the arc therefore represents an effective resistance which very greatly decreases with increase of current. With increase of current, however, the arc considered as conductor changes its shape, that is, increases in section.

As illustration, such volt-ampere characteristics are, with the current as abscissae, and the total voltage as ordinates, shown for the magnetite arc in Fig. 6, for arc lengths of $\frac{1}{8}$, $\frac{1}{2}$, 1 and $1\frac{1}{2}$ in.

The voltage e consumed by the arc can be resolved in two components:

$$e = e_0 + e_1$$

1. I once suspected that the abnormal character of the carbon arc may be due to the infusibility of carbon at atmospheric pressure, where the melting point is above the boiling point. Arsenic metal, however, which also has a lower boiling point than melting point, does not seem to maintain an alternating arc.

where e_1 is the voltage consumed by the resistance of the arc stream, e_0 the potential drop at the terminals, which changes less with change of current or is constant and independent of the current, as in the mercury arc and probably the magnetite arc and many other arcs.

Approximately, the section of the arc stream can be assumed as proportional to the current:

$$i = c_1 s = c_2 d^2$$

where s = section, d = diameter of arc stream.

The power consumed by the arc stream is:

$$w_1 = e_1 i \tag{1}$$

The temperature of the arc stream probably is the temperature of the boiling point of the cathode material, hence independent of the current, and the power radiated by the arc proportional to its surface, hence:

$$w_2 = c_3 d l_1$$

where l_1 = effective length of arc stream.

Since the power consumed by the arc stream must equal the power radiated by it, we have

$$w_1 = w_2$$

or

$$e_1 i = c_3 d l_1 \tag{2}$$

and, eliminating d from equations (1) and (2):

$$e_1 = \frac{c l_1}{\sqrt{i}}$$

Due to the heat conduction of the arc stream to the electrode, the effective length l_1 is probably slightly greater than the actual length l of the arc, hence:

$$l_1 = l + a$$

Therefore:

$$e_1 = \frac{c (l + a)}{\sqrt{i}}.$$

and

$$e = e_0 + \frac{c (l + a)}{\sqrt{i}}$$

This equation of the volt-ampere characteristic of the arc contains the three constants e_0, c and a. It is a rational formula, but can be approximate only, since the assumptions on which it is based are only approximate.

From the observed volt-ampere characteristics of Fig. 6 for currents 2, 3, 4, 6, 8 amperes, the corresponding voltages have been taken and for each arc length the average value of $c\ (l + a)$ determined as 190, 128, 69, 21 for the arc lengths of 1½, 1, ½ and ⅛ ins. Therefrom then follow the averages:

$$c = 125$$
$$a = .05''$$

and the calculated values of $c\ (l + a)$: 190, 129, 68, 21.5, which is a very good agreement.

This then gives the equation:

$$e = 30 + \frac{123\ (l + .05)}{\sqrt{i}}$$

From these equations the values of e have been calculated for the currents 1, 2, 3, 4, 6, 8 amperes, and marked in Fig. 6 by circles. As seen, considering the approximate character of this rational formula, the agreement is remarkably close except for very low currents. For very low currents, however, the arc stream is very thin, the energy radiated therefore is disproportionately large and the observed voltage must therefore be expected to be higher than calculated.

Since this equation is based on the assumption that the section of the arc stream is proportional to the current, it can not apply to the mercury arc in vacuo, in which the section of the arc stream is constant, is the inner diameter of the arc tube, but the vapor pressure varies with the current.

The volt-ampere characteristics of the mercury arc (16 in. length, ⅞ in. diameter) is shown in Fig. 2 and differs, indeed, very greatly from that of an arc at atmospheric pressure; the voltage is approximately constant over a considerable range, but rises for low currents and also for high currents.

Assuming the conductivity g of the vapor stream as proportional to the amount of mercury vapors, that is, the vapor density δ

$$g = c_1\ \delta$$

and the amount of mercury vapors as proportional to the current, which can be approximately correct only within a limit.

$$\delta = c_2\, i$$

We have: —

$$g = c\, i$$

and therefore the voltage consumed by the arc stream

$$e_1 = \frac{i}{g} = c$$

that is constant.

Epecially for low currents the amount of mercury vapors, or the vapor density, must be less, due to the heat conduction from the cathode point, as discussed before. Assuming this as approximately constant, a negative corrective term: $-a$ is introduced into the conductivity.

Especially at high currents the conductivity is decreased due to the increase of temperature of the arc. Assuming this as proportional to the power consumed in the arc, $e\,i$, or approximately i^2, introduces another negative corrective term, $-b\,i^2$, and the conductivity becomes

$$g = c\,i - a - b\,i^2$$

Hence the voltage consumed by the arc stream

$$e_1 = \frac{l}{c - \frac{a}{i} - b\,i}$$

And if e_0 = potential drop at terminals

$$e = e_0 + \frac{l}{c - \frac{a}{i} - b\,i}$$

which would be an approximate rational formula for the volt-ampere characteristics of the mercury arc in vacuo.

As seen, this equation gives a curve of similar shape to that observed: approximately horizontal, but rising at both ends.

Taking from the observed volt-ampere characteristics in Fig. 2 the values of e for i = 2, 3, 4, 5, 6, 8, 10 amperes, and calculating therefrom the constants, we have the values

$$c = .0813$$
$$a = .056$$
$$b = .0042$$

Hence

$$e = 13 + \frac{100}{8.13 - \frac{5.6}{i} - .42\,i}$$

From this equation, values of e are calculated and marked by crosses on Fig. 2. As seen, the agreement between the calculated values and the observed curve is fairly good, considering the above formula is only a first approximation. Only for low currents a greater difference occurs, but must be expected since by the insertion of inductance into the circuit the cathode conditions are considerably modified, and also at such low currents the path of the current may not completely fill the tube.

VIII.

From its drooping volt-ampere characteristic results the unstability of the electric arc on constant potential, since a decrease of current, or tendency thereto, by increasing the voltage required by the arc, would on a constant potential supply cause a still further decrease of current and extinction; while an increase of current, by

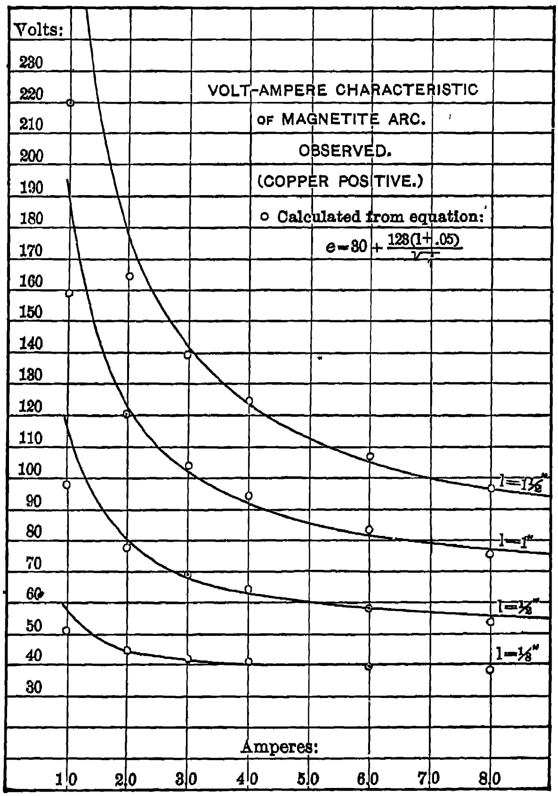


FIG. 6.

decreasing the voltage required by the arc, causes a still further increase of current and ultimate short circuit. Only such a circuit can be stable on a constant-potential supply in which an increase of current causes an increase of consumed voltage and inversely, and any tendency to a change of current so checks itself. This, for instance, is the case with an ohmic resistance and the insertion of

a resistance in series to the arc therefore reduces its unstability and ultimately gives steadiness.

Let in Fig. 7 as curve *I* be reproduced the volt-ampere characteristics of a magnetite arc of 1 in. length. The voltage consumed by 10 ohms resistance is a straight line *II*. Inserting thus 10 ohms resistance in series to the arc, the total voltage consumed

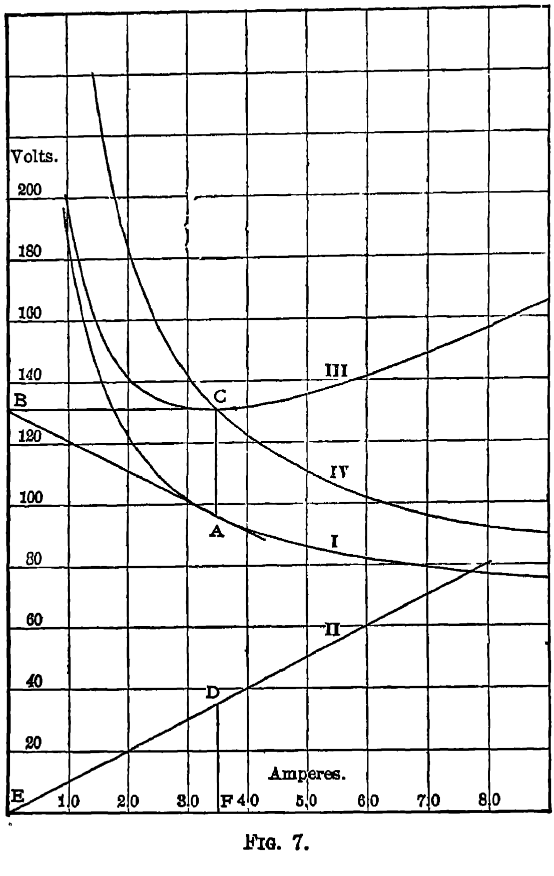


FIG. 7.

by the arc and resistance is given in curve *III*. Beyond 3.5 amperes this curve is rising and the arc therefore stable. Below 3.5 amperes it is still drooping and the arc unstable, and an attempt of operating the arc, say at 2 amperes 142 volts, results either in the arc going out or the current rising to 6 amperes, where the arc becomes stable on the rising branch of the curve.

The point 3.5 amperes 132 volts therefore divides the curve *III*

into a stable and an unstable branch, and gives the minimum voltage of supply at which a 3.5-ampere arc of 1 in. length between magnetite terminals can be operated.

To every value of current thus corresponds a value of voltage which is the minimum supply voltage required for stability of the arc, and these points give a "stability curve" *IV*.

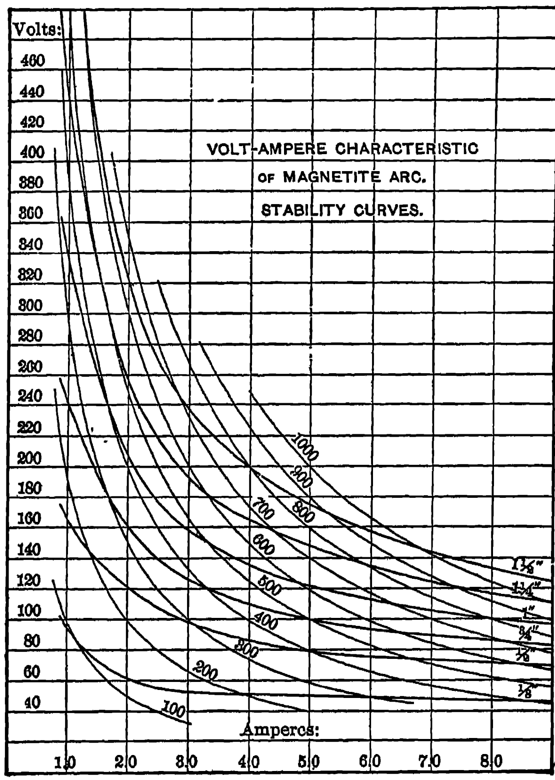


FIG. 8.

Drawing a tangent to the volt-ampere characteristics at 3.5 amperes, in *A*, and connecting the intersection *B* of this tangent and the ordinate axis, with the point *C* of the stability curve, the triangle $ABC \cong DEF$; hence $ABC = 90$ deg., and *BC* is horizontal. The ordinates of the stability curve therefore are the intersections of the ordinate axis with the tangents of the volt-ampere characteristic.

Since the stability curve *IV* represents the voltage at which the

arc passes from unstable to stable condition, in practical operation a margin beyond the voltage value of the stability curve has to be allowed.

In Fig. 8 are plotted in heavy black lines curves for magnetite arcs of 1/8, 1/2, 3/4, 1, 1 1/4, 1 1/2 in., so that the stability curves are 10 per cent below these curves; that is, these curves in Fig. 8 are 11.1 per cent above the stability curves. These curves are of practical importance in considering the operation of the arc on constant-potential circuits. In steeper lines are shown the equilateral hyperbolas of constant power, from 100 to 1000 watts.

To illustrate the use of these curves:

A 400-watt magnetite arc (the power here including that consumed by the steadying resistance) of one inch length requires a supply voltage of 240; a 3/4-in. arc requires 123 volts; a 1/2-in. arc requires 80 volts.

The longest 400-watt arc which can be operated from a 125-volt circuit is .76 in., and consumes 3.2 amperes. The longest 300-watt arc is a .63-in., 2.4-ampere arc.

On a 125-volt supply circuit the arc lengths corresponding to different currents are as follows:

Arc length, inches..........	1/2	3/4	1	1 1/4	1 1/2
Current, amperes...........	1.9	3.15	4.8	6.9	9.1
Voltage consumed by arc proper, volts.............	82	84	87	90	94
Hence, per cent steadying resistance	34.4	32.8	30.4	28.0	24.8

Similar characteristics exist for the carbon arc, etc.

IX.

The most important application of the electric arc is for illumination.

From the electric arc light can be produced:

1). Directly, by the heat produced at the anode, bringing the anode to incandescence.

2). Indirectly, by the heat at the anode evaporating constituents of the anode, which, entering the arc stream, gives a luminous spectrum.

3). Directly, by the arc flame, by using as carrier of the current in the arc flame a cathode material which gives a luminous spectrum.

1). When using the incandescence of the anode for illumination, carbon is still exclusively used, since it is most refractory, the carbon arc the hottest arc, and so the luminous efficiency of the anode tip of the carbon arc the highest efficiency available by incandescence.

Since the carbon-arc flame is practically non-luminous, but consumes voltage, the shortest arc length by which the shadow of the cathode does not yet seriously obstruct the light is the most efficient.

The smaller the anode diameter the less is the loss of heat by conduction and the greater the efficiency, but, also, the greater the rate of consumption of carbon. Efficiency is, therefore, to be balanced against life in determining the carbon diameter.

In this class of illuminates would probably be counted also those arcs in which, as anode, a material is used giving a strong heat luminescence, as mixtures of rare earths, in which case then, at a temperature probably lower than that of the carbon arc, higher efficiencies may possibly be secured.

2). To produce light from the arc flame by introducing by evaporation substances which give a luminous spectrum, carbon, as carrier of the arc, is exclusively used since it gives the hottest arc, and the material fed from the anode as the hottest terminal, while as cathode frequently a plain carbon is used. The rate of consumption of electrodes must be fairly rapid to feed the coloring matter into the arc in sufficient quantities to give a good efficiency. The number of substances which give a high efficiency and satisfactory color is rather limited. Calcium compounds are commonly used since the calcium spectrum is of very high efficiency. Its color, however, is orange yellow and such an arc, therefore, gives strong monochromatic effects, which are not always desirable.

3). When using substances as carriers of the current in the arc stream which give a luminous spectrum, carbon is excluded by the low luminosity of its arc flame. The material is used as cathode and the anode may be non-consuming. The temperature of the arc ceases to be essential, since the light is produced more or less directly by electro-luminescence and the arc temperature may be far below incandescence, as in the mercury arc. By using substances which are stable in the air at high temperature, as metallic oxides, the rate of consumption of electrodes can be made very small without losing in efficiency. The metals of the iron group seem to give the highest luminous efficiency, combined with

white color of the light, and their oxides, which are not attacked by the air even at high temperatures, are, therefore, commonly used.

In this class also belong most vacuum arcs, such as the mercury arc.

DISCUSSION.

CHAIRMAN LIEB: Gentlemen, we have all listened with very great interest to Dr. Steinmetz's paper, which shows the result of keen analysis and careful investigation of the phenomena of the electric arc. We have several other papers on similar subjects, relating to the arc, and with your approval we will read several of them and then have a joint discussion of several of them so as to economize time. I will say that several of the papers arrived at the very last moment, and therefore are not in print, but we have the illustrations which go with them.

I will call upon Dr. Louis Bell to read the paper of Prof. André Blondel on "Impregnated Arc Light Carbons."

Dr. BELL read the paper.

PROPERTIES AND INDUSTRIAL APPLICATIONS OF THE ELECTRIC ARC, PRODUCED BY MEANS OF ELECTRODES OF CARBON MIXED WITH MINERAL SUBSTANCES.

BY PROF. ANDRÉ BLONDEL, *École des Ponts et Chaussées, Paris.*

THE DIFFERENT KINDS OF ELECTRODES AND ELECTRIC ARCS EMPLOYED TO-DAY IN ELECTRIC LIGHTING.

Until very recently the only method of arc lighting was from the arc between carbons. It is true that experiments had been made with other electrodes, as we shall see later; but these experiments, often badly made and too quickly generalized, had led to the belief that carbon, having the highest point of volatilization, gives an arc of the highest temperature, and consequently, of the highest efficiency. It is only during the last few years, particularly since the discoveries of Aüer and Nernst, that we have understood that the efficiency is not alone a question of temperature, and that certain substances enjoying an emissive power more or less selective — that is to say, a spectrum of emission different from that of black bodies and favoring the yellow and green radiations — might produce light more economically at a temperature below that of incandescent carbon at its point of volatilization. It was natural from that time to undertake researches upon the employment of substances other than carbon for the production of the arc. The arc between electrodes formed of mineral substances thrust itself almost involuntarily upon the attention of many observers (Nernst, Rasch), when in the course of studies upon the glower of the Nernst lamp, these glowers happened to break. But the lack of conductivity of such electrodes when cold being an obstacle to their employment, Rasch and others sought vainly to overcome it by the addition of a conducting core or envelope. They were then led logically to make artificial conductors by the use of conducting substances, such as carbon in mixture with the mineral substances. This is what was done in 1878 by M. Bremer. By a happy circumstance the latter, who was not an electrician, and unlike many contemporaneous specialists, ignored the studies made and the results

obtained previously upon carbons of that nature, was not discouraged or halted by the inexact scientific prejudice as to the necessity of high temperatures. Moreover, his researches, often ill-directed, were followed with remarkable perseverance and crowned with a legitimate success, notably, at the Exposition of Paris in 1900. They reopened a subject which had appeared to be closed, brought into light forgotten work, and excited anew on the part of numerous seekers, including the author of this communication, a desire to increase the means of the production of electric light, and to combat the alarming progress of gas lighting.

In a like manner, but in another order of ideas, the very interesting discovery of a young inventor, Mr. Cooper-Hewitt, who simi-larly was not stopped by the discouraging experiences of older inventors, called attention to the arc in mercury which had fallen into forgetfulness since the work of Arons; and the studies which have been made on this subject from many sides have thrown a new light upon the phenomena of the electric arc and opened also new ways for inventors in the search of economical electric arcs, not only through the employment of mercury or the alkaline metals, but also of the conducting oxides, such as oxide of iron.

In the present state of our knowledge the different kinds of electric arcs which interest the electric-lighting engineer, may be classed as follows, from the point of view of the nature of their electrodes.

1). Arcs between pure carbons.

2). Arcs between metals.

3). Arcs between oxides or compounds of pure metals.

4). Arcs between mixed electrodes, composed of carbons mixed with mineral substances.

The first category is characterized by the fact that the arc properly so called does not give much light, while the electrodes, especially the anode, become very brilliant.

In the second category mercury (or its alloys) is the only metal at present utilized, since its vapor becomes luminous in the arc although the temperature is very slightly raised, thanks, without doubt, to a particular phenomenon of luminescence. The other metals, such as iron, give an arc much less brilliant and are utilized only for the production of violet or ultra-violet rays in medical or photographic applications.

The arc of mercury itself, on account of its lack of red rays in the spectrum, finds in these two applications its principal use to-day.

Moreover, by placing it in a tube of silica (constructed by Heraus) in place of glass, which absorbs the ultra-violet rays, it has recently been found to constitute a source of very powerful chemical radiations comparable to the arc from iron.

The arc between metals has luminous properties very different from those of the arc between carbons. The electrodes are brilliant only over a very small surface and with a brightness very inferior to that of the crater of an anode of carbon. The arc is longer and becomes the principal source of radiations. This is why we are interested in lengthening it and making it play in a vacuum, as is possible with the mercury arc.

The third category, which includes the arcs between metallic oxides, was studied first by Rasch, using the oxides of feeble conductivity, giving short arcs; then by Steinmetz, with conducting oxides, permitting him to attain long arcs. In both cases the electrodes play only a small role in the production of the light, which comes more from the arc, properly so called, formed of the very brilliant vapors heated to a high temperature. But Rasch, in his "Electrolytic Arc" (German patent 113,594), suggested the arc between carbons and employed two like electrodes formed of oxides called "conductors of two species" (after Nernst), while Steinmetz suggested the arc of mercury, employing an electrolytic substance only as the cathode, and a pure metal for the anode. We will see that these two methods involve great differences. As the temperature of the cathode is much inferior to that of the anode, Rasch was able only to employ refractory oxides, which gave short arcs, while Steinmetz utilized an easily fusible oxide (magnetite) and obtained very long arcs.

Finally, the fourth category comprises lamps using four different types of electrodes: Solid carbons, formed of a paste of carbon containing mineral substances in more or less high proportions (carbons of Bremer); carbons with cores in a cylinder of pure carbon, containing one or several longitudinal canals of small sections, filled with mineral substances only, or preferably mixtures of carbon ("flaming carbons" so-called, of Siemens Bros. and other manufacturers); carbons mineralized in the paste and supplied with mineralized cores similar to those of other electrodes (carbons of Bremer); finally, carbons with an envelope formed of a solid mineralized cylinder as core and a thin envelope made of non-scarifiable carbon, which preserves the interior cylinder (carbons of the author).

In the present communication, I will occupy myself more especially with the arcs of the fourth category, involving different kinds of "mixed carbons," also called "impregnated" carbons (for the substances are added in the dry state in the paste). I refer to other categories only for theoretical or experimental comparisons.

Origin of "mixed carbons" of mineral substances.

Numerous inventors have for a long time studied the results obtained by adding either in the carbon paste or as a coating, and either in the central core or by absorption, various mineral substances. The older researches go back to Casselmann (*Annals of Poggendorff,* 1844, Vol. 63), who introduced into the carbons borates and sulphates and boric acid. Since that time mineral matters have been employed in four different ways: To reduce the lateral combustion; to augment the conductibility of the arc and render the combustion more regular; to make the slag run freer, and, finally, to increase the light.

1). *To reduce the combustion.* Wortley, for example (French patent No. 129,636, 1879), adds silicates to the paste. Lacombe (French patent No. 509,170, 1890), adds to the same sulphates, chlorates, and phosphates, etc., incorporated after or before moulding. It is a known practice among all manufacturers of carbons to add for the same purpose boric and phosphoric acids. Mignon and Rouart (143,206, 1881) claim a vitrified exterior coating Julien (French patent 265,661, 1896) has also claimed this process as well as one employing silicates, tungstates, and similar slow burners. (The salts of lime, magnesia, soda, and potash, should act as retarders.)

2). *To augment the conductibility in the arc.* Carré, in 1886 (French patent No. 174,268), claimed, in order to render the light more fixed, the addition to carbons by impregnation or by mixture before moulding, of borates of soda, potash, magnesia, lime, etc. In two other patents (179,058 and 218,097) he claimed the employment of the same substances and several others, notably of all the insoluble salts of lime, magnesia, strontium, and aluminum, in an axial core. Siemens & Halske patented in 1879 in various countries an analogous idea, and in Germany a process of soaking similar to that of Casselmann (*Elektrotechnische Zeitschrift,* 1895, page 553). Mr. Faissner has insisted upon the particularly favorable action of boric acid added thus to the carbons. The employ-

ment of boric acid and of its alkaline source has been very general for the last few years to make the arc more stable.

3). *To make the slag run freer.* Carré suggested the addition of potash and soda, not only for lengthening the arc and making it regular, but also as a flux to make the silica and other impurities contained in the retort carbons, flow as globules from the ends of the carbon (Du Moncel, "*Exposé des App. de l'Électricité,*" Vol. 5, page 470.) More recently M. Bremer has shown more definitely the benefit of adding a flux, especially when the carbon contains a large proportion of the salts of lime or magnesia, the difficultly fusible slags of which are thus softened and more easily gotten rid of (French patents, 291,037 and 291,106, 1899).

4). *To increase the light.* This application, which is the most interesting to us for the moment, has been known for a long time. It is stated particularly in the treatise of Du Moncel, already cited (Vol. 5, page 470, 1878), that in 1876 Gauduin discovered and patented the fact that the addition of salts of lime in a sufficiently high proportion, notably the phosphates of lime to the amount of 10 per cent (which corresponds to more than 5 per cent of lime) doubles the light for an equal section of carbon, and that the luminous power of carbons of small diameter (*Ibid.*, page 472) is much greater than that of carbons of large diameter. He obtained, also, analogous results with oxides, chlorides, silicates, and aluminates of lime. The same salts of magnesium gave, as well as pure magnesia, analogous results, but not so advantageous.

Archereau and Carré (*Ibid.*) made similar statements in 1877 concerning the salts of calcium, magnesium, and strontium incorporated in the paste of carbons, whilst Jablochkoff (German patent 663) employed clay and kaolin not only to insulate his candles, but also to fill the central cores. Rapieff in 1878, in his lamp with converging carbons, understood also the use of carbons containing mineral substances.

MM. Michel and Barraud (French patent 191,720 of 1888) also claimed the addition to the paste of carbons of magnesia, lime, or kaolin in some proportion. In the French patents already cited (291,037 and 293,806 of 1899), Bremer claims all carbons containing more than 5 per cent of mineral matter, with the addition of a flux for the purpose stated above. In another patent, 291,106, he claims the fluorides, bromides, and iodides of lime, the only salts of lime and magnesia of which Du Moncel had not made mention in the treatise cited above, and which give to the light, according

to Bremer, a yellow tint more agreeable than the other salts of lime, which give the light a more ruddy tint.

In the United States attention was called equally early to the employment of mineral substances in the carbon. In 1878 (U. S. patent 210,380) Weston suggested the employment of single and double metallic fluorides in the place of oxides, either surrounding the carbons or mixed with the paste in a proportion not indicated, but which, according to the description, must be quite large. In 1890 Head and Sanderson took up this study and occupied themselves with the introduction of mineral substances both in the total mass and in a central core; but these carbons were prepared not by filling, as in the Siemens' carbons, but by sheathing, and it is difficult to know truly what end was sought. Their patents (U. S. patents 421,469 and 422,302) include an incoherent list of simple and compound bodies which contains nearly all the refractory or coloring bodies of chemistry, between which no distinction is made, and many, to my understanding, are more deleterious than useful. Only the proportions of the mineral substances are stated clearly; the paste of the carbons might contain from 1 to 10 per cent of refractory substances, and from 1 to 20 per cent of coloring substances; or the central core might contain from 1 to 20 per cent of refractory, and 1 to 20 per cent of "coloring" substances (refractory substances).

Another patent was taken out in 1900 by J. Sander (English patent 9260) which claims the employment — very difficult to understand — of a reducing agent added to the salts for increasing the light. I have found nothing in the results of the tests of these various carbons to show that they reduce the slag and smoke to a less troublesome extent than in the tests of Gauduin.

Researches of M. Bremer.

It is to M. Bremer that the honor belongs of having first manufactured mineralized carbons, but the first lamp for utilizing them was an usual arrangement, of which I shall make a comparative criticism later. The researches of M. Bremer were completed in 1898, if we may judge by the English patent (No. 16,552) which refers only to the addition to the carbons of infusible compounds of lime or magnesia. As he does not speak of slag, it is necessary to conclude that these very refractory substances were added only in small quantities; he counsels this as a means of obtaining a more steady light, employing as the positive electrode a pure car-

bon and as the negative electrode a mineralized solid carbon placed above. There was nothing new in these carbons in view of the work of Gauduin, of which work the inventor was ignorant. In 1899, M. Bremer took out a series of German patents (Nos. 118,464, 118,867, 127,333, 114,314, 114,242, 113,993, 133,703) which refer especially to mineralized carbons, and which are the prototypes of the principal foreign patents. He claims in particular the following characteristic points, the bearing of which the patents of Weston, Sanderson, etc., must, without doubt, limit.

The addition of mineral substances to the base, such as compounds of calcium, strontium, and magnesium, in the proportions of from 20 to 70 per cent, for securing a long and brilliant arc. The addition of the salts of fluorine, bromine, and iodine, in the proportions of at least 5 per cent, to color the light yellow, and of the salts of boron (without doubt boric acid), potassium, and sodium to secure a more regular light. The addition of a flux such as glass, borax, or the alkaline silicates, etc., either surrounding the carbons or in the mass itself, to soften the refractory calcareous slag, and to facilitate its falling away in drops.

This employment of fluxes clearly shows, as does its mention in other patents prior to those of M. Bremer, that the great difficulty of removing the slag which forms in the arc between the vertical carbons was understood, because (as is shown in the same patents), he employed a mineralized upper carbon (without protective envelope) placed above the negative in order to utilize the light of its crater in the best possible manner. Under these conditions the mineralized materials are volatilized or melted only if very fusible (such as the phosphates), or when fluxes are added (such as the borates or boric acid); but then the drops of melted slag fall upon the negative pencil and obstruct it. To remove this inconvenience M. Bremer has increased the density of the slag in order to make the drops run; the final result being still unsatisfactory, he has been led to change the position of the negative carbon, putting it no longer below but at the side and nearly parallel to the positive carbon. He thus produced a special type of electric arc (Fig. 1), to which he has been able to give the necessary stability only by placing it in an intense magnetic field, skillfully compounded, which projects the arc below in the form of a crescent, instead of being allowed to rise above, following its natural tendency.

In this manner the slag flows away easily, the arc is almost stable,

and the efficiency is better than with carbons one above the other as in the ordinary arrangement.

Finally, to retain the vapors which are disengaged, the same inventor has surrounded the points of his carbons with a truncated metallic cone, serving, as he thinks, to increase the efficiency by concentrating the heat of the arc, and also to retain the gases of combustion around the carbons in such a manner as to equalize automatically the combustion of the two parallel carbons. To regulate the feed of these, M. Bremer had recourse at first to four carbons, arranged two and two, as in the lamp of Girard of 1879 (who also employed the magnetic field blowing downward); and afterward to a system of regulating by steps, combined always with the magnetic field, which is absolutely necessary. M. Bremer thus finally

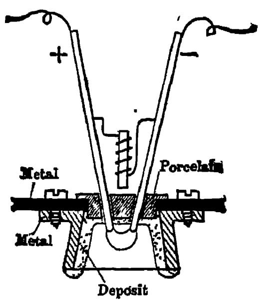


FIG. 1.—BREMER ARC LAMP.

arrived, in 1900, at his well-known combination, forming a very interesting whole, of which all the elements are necessary to the success of the arrangement. He has, however, stated repeatedly, notably at Berlin on the 25th of March, 1901,[1] his conviction that it is not possible to use mineralized carbons in lamps with vertical electrodes, and that it is necessary to employ converging electrodes with their points turned downward in order that the slag may flow away in drops without interfering with the regular action of the arc.

The Bremer lamp was exhibited at the Exposition of Paris in 1900 and was an object of much interest there. Its inventor has added to it since then numerous improvements of mechanism which I will not describe here.

The photometric results obtained at that time, which have been

1. *Elek. Zeit.*, 1901, April 4, p. 304.

published by M. Wedding,[2] and by M. Laporte,[3] were inferior to those now obtainable; the carbons contained principally fluoride of calcium and borax and gave a very yellow light, somewhat disagreeable, but which has been much improved since.

Researches of the Author.

About this time, 1900, being struck by the defects of converging carbons with respect to symmetrical distribution of the light rays and lack of steadiness of the light, and of the imperfect arrangement of the mechanism of the Bremer lamp, I undertook, in my turn, a study of the problem of mineralized carbons in the hope of obtaining a lamp with a reflector and employing vertical carbons. I employed at first carbons of varying composition with electrodes of greater length, producing an electrodynamic rotation of the arc to render it steady, but I had to renounce this idea since this rotation, which enlarged the base of the arc, diminished very greatly the efficiency. In order to concentrate and aid the flow of the slag from the arc, the anode (strongly mineralized) was placed at the bottom, below a cathode, pure or slightly mineralized, shielded by a hood from cooling (without which precaution all vapors would condense upon it). Later I discovered that if I increased the mineralization beyond 25 per cent, it was necessary to get rid of the slag to prevent the oxidation of the carbon which served as a support to the mineral materials, and I was then led to preserve the mineralized carbon by a thin envelope made of pure carbon which forms a shield up to the incandescent point; the thickness of the envelope must be determined so that it will burn a little more slowly than the mineralized portion, and the arc must be always maintained upon the latter, which it will not completely cover, and must never form upon the pure carbon, which gives a short and dim arc. This envelope of which the thickness in general is 1/5 to 1/7 of its diameter in a lower anode of my lamp, and which must be still thinner in lamps with converging carbons, has then a purpose very different from that of the thick mantels of the cored carbons (Dichtkohlen, Effektkohlen) of German manufactures; in the latter the arc covers not only the entire core which burns, but also the mantel of carbon and tends to be displaced and to quit the core when currents of high density are employed. On the contrary, with my carbons the very contracted base of the arc

2. *Elek. Zeit.*, 1902, Feb. 22.
3. *Bulletin* Soc. Int. des Elec., July 3, 1901, pp. 364, 365.

wanders over the mineralized body without a chance of changing color, and we may then use densities of current lower than in ordinary carbons without the danger of slag. With higher current densities comparable to those of cored carbons, one may add advantageously one or several cores rich in salts of potassium which concentrate the arc and aid the economy. Finally, to improve the quality of the light and its steadiness, I have undertaken with the collaboration of Mr. Dobkevich — the assistant in my laboratory[4]— a series of researches upon the influence of various mineralized materials and the best proportions of each component of the electrodes. We have been led to understand with M. Bremer that the salts of calcium are those which offer the best economy, notably the fluoride of calcium, but we add to it "regulator" salts which augment the light and render it more white and more steady. The quality obtained to-day appears to escape the reproaches addressed formerly to this species of carbon, and very good results are attained with alternating currents as well.

A study of this nature is unhappily confined to the empirical method, for we know nothing of the general laws of the radiation of mineral vapors at high temperatures, and spectrum analysis has been able only to show us that the spectrum of the mineralized arc is of brilliant discontinuous bands without our being able to establish the laws of correlation between them and that of the component bodies. In particular, the spectrum obtained by means of fluoride of calcium bears no resemblance to that of the other salts of calcium, and it is, moreover, more brilliant.

Another important advantage of the employment of a pure or slightly mineralized upper electrode is that it permits of the easy relighting of the arc, since the point of the lower electrode is not covered with slag, while if the upper electrode is strongly mineralized, there will remain a drop of slag which becomes an insulator when it cools.

4. I have pleasure in speaking of the very excellent aid of Mr. Dobkevich to add that he has been my assistant during all these studies, and has taken a most active part throughout the execution of all the experiments and of the photometric measures. Latterly he has collaborated also in the getting out of the latest model of the lamp (1904), and it is he who has directed and brought to the commercial stage the carbons of the French Society of Incandescent Gas Lighting (Aüer System) of which he is now the laboratory director. This work has not been without the encounter of serious difficulties, over which he has been able to triumph completely.

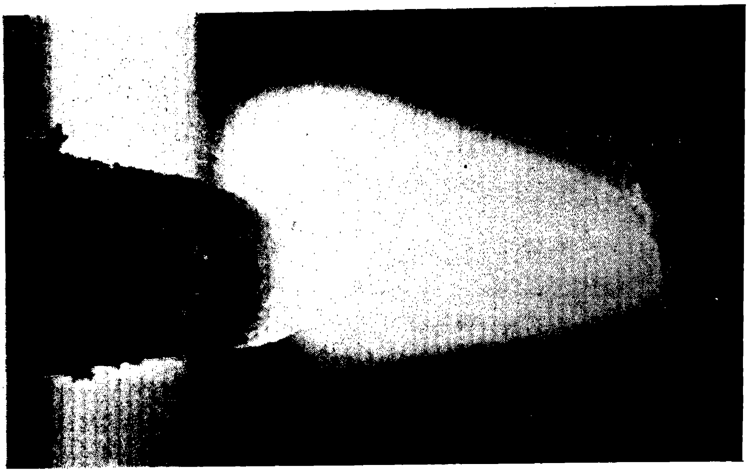


Fig. 3.

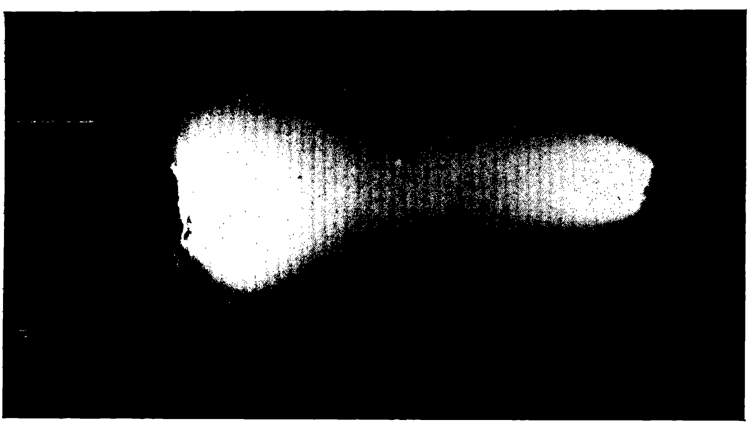


Fig. 4.

LAMPS OF THE AUTHOR.

The lamps I have made to use with coated carbons are, as in the case of lamps for the flaming arc constructed in Germany, of the type known as open-arc lamps, but they are distinguished by some characteristic peculiarities. In order to prevent the fumes from escaping, the globe is closed at its upper part by a shutter, through which the lower part of the carbon passes in a central insulating bushing, which is surrounded by a condenser or reflector of refractory matter, or of metal, which retains the greater part of the vapors. Unlike the construction of the Bremer lamps, this

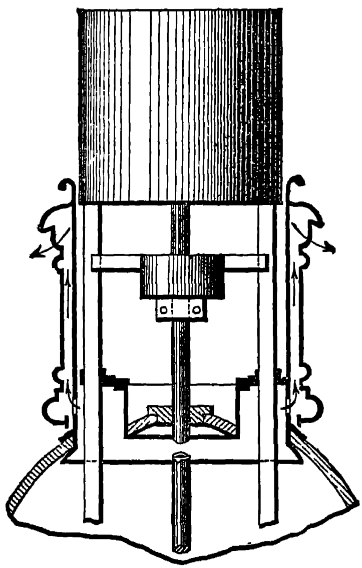


FIG. 2.—BLONDEL ARC LAMP.

condenser is large and very wide, in order that the fumes near the arc may be condensed rapidly by offering a large surface of deposit. The gas finally passes outside by way of openings through the protecting shutter. In another type the gas follows a much longer route through vertical holes to a chamber with double walls (Fig. 2), surrounding the upper portion of the lamp, with openings or fixed tubes below to conduct the gas outside of the compartment. The globes of these open-arc lamps are furnished with an opening to facilitate the circulation of the gas. I have also made a type of inclosed arc lamp in which the gas, instead of es-

caping, circulates in closed passages and deposits therein the solid matter as fast as produced.

The mechanism of these lamps is differential and resembles that of open arc lamps, but differs in special details suggested by experience, notably having an angle of illumination much greater, reaching 10 to 25 per cent in place of 3 to 5 per cent with lamps with ordinary carbons, and having a greater sensitiveness and rapidity of action. My most recent type, devised with the collaboration of M. Dobkevitch, is more simple than those just described, realizing better the conditions above and in damping of oscillations. It is applicable to both inclosed and open arcs and to alternating currents, as well direct currents, by modification only of the electro-magnets.

Having thus described the carbons and the lamps, I will now discuss the arrangements, the theoretical considerations, and experimental results.[5]

Characteristic Aspects of the Arcs of the Lamps of the Author.

These are in general composed of the alkaline earth bases, which give the best results from the point of view of the production of light, as was noted 25 years ago by Gauduin, Archereau, and Carré. In the experiments here detailed, I have considered more particularly the case of solid electrodes formed of an intimate mixture of carbon and of one of the salts of calcium, notably the fluorites, which are particularly suitable for this application. Since the employment of cores containing the same mineral substances caused the arc to form partly upon the core and partly on the carbon and pass sometimes from one to the other, these will not be considered.

The principal phenomenon which has been noted before with the mixed carbons is the lengthening of the arc. For equal voltage, a continuous-current arc easily quintuples its length with respect to arcs between solid carbons. Besides, the aspect of the arc with strongly mineralized carbons becomes quite abnormal (see Figs. 3, 4); there is no longer upon the positive carbons a great and very brilliant crater, but merely a very small surface of vaporization giving a light not much superior to that of the arc, which becomes extremely brilliant over a certain length. It is the arc which becomes

5. I have been helped particularly with photographs and curves by Messrs. Ragonot and Bethinod, who have done excellent and active work for me, and I thank them here.

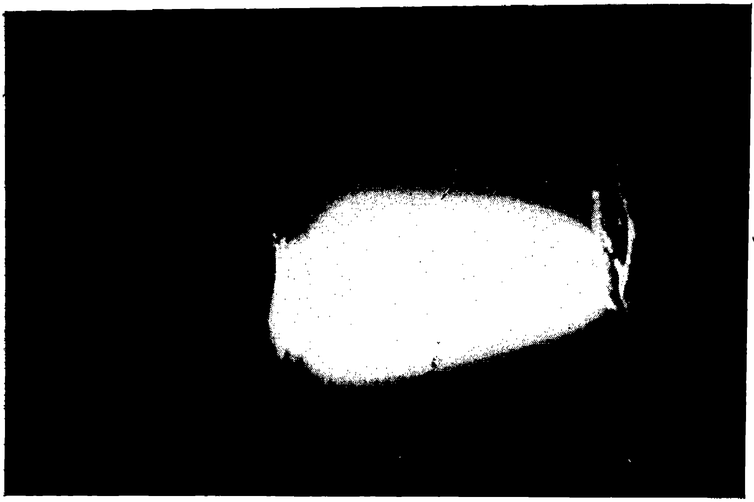


Fig. 5.

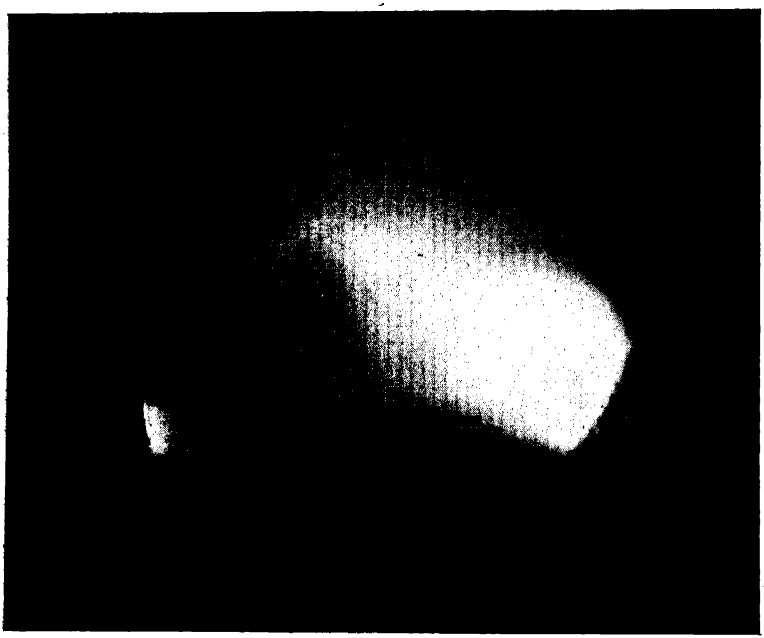


Fig. 6.

the principal source of light; another brilliant spot is formed upon the surface of the negative carbons, of which the light is comparable to that of the positive, but the arc remains large and cloud-like at the negative carbon when the latter is below and of pure carbon, and forms often a brilliant brush. It attaches itself to the positive carbon if the negative carbon is below and mineralized (Figs. 4, 5).

However, if one increases progressively the proportion of mineral substances, the arc grows shorter, and if it happens to come to a spot purely mineral, such as a pocket of lime or of burnt magnesia, it becomes very short. This results in practice in continual and important variations of the lengthening of the arc between mineralized carbons, according as the vaporization of the mineral substances is more or less active. The maximum lengths appear to be reproduced with the mineralizations between 20 and 30 per cent.

The existence of this seeming maximum may be explained by the phenomena of ionization in the arc, of which I will speak further on in detail.

Analogies between the Arcs between Mixed Carbons and the Arcs between Pure Carbons or between Metals.

It is very curious that the arc saturated with the mineral vapors of the salts of calcium such as we have mentioned presents the same characteristics as to quality as the arc between solid carbons, as compared with arcs between ordinary cored carbons, of which the ordinary core is formed of a mixture of carbon with the salts of sodium and of potash. The first of these characteristics, established by the remarkable and to-day classic work of Mrs. Hertha Ayrton,[6] is in that the law of variation of the voltage between the electrodes as a function of the length of the arc at a constant current intensity, is linear, within the particular limits I employ. Now it follows from the analogous curve (Fig. 7) relating to 4 carbons of 10 mm containing about 50 per cent of mineral matter, with a current of from 3 to 5 amperes, that the voltage varies very sensibly from the linear law in limits from zero to 30 per cent.

A second characteristic of the solid carbons, which I established in 1892,[7] and which, as I have stated since, is common to them and

6. H. Ayrton, "The Electric Arc," London, 1902.
7. Société Française de Physique, April, 1892; International Electrical Congress at Chicago, 1893; and above all "New Researches upon the Alternating Arc" in *La Lumière Électrique*, September, 1893.

to the pure metals, is that they give with alternating currents an arc of a disruptive nature; that is to say, presenting sudden bursts of light with a rise of voltage in each cycle, which is particularly in evidence when the feed circuit is non-inductive. I have then been led to study, by means of the oscillograph, as in my preceding work upon the alternating arc,[8] the periodic curves of the arc between mineralized carbons. Figs. 8 and 9 represent the curves thus obtained with currents of 8 or 9 amperes with carbons similar to the preceding, but of 9 mm diameter. Fig. 8 was obtained on a non-inductive circuit and Fig. 9 on a circuit with considerable self-induction. We may say that these curves have precisely the form typical for solid carbons, while carbons with ordinary cores give rounder curves and without extinction with prolonged current.

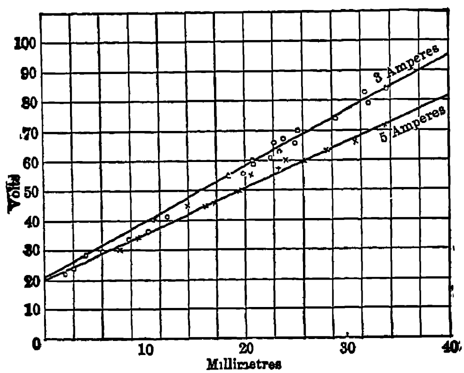


FIG. 7.

The limy mineral vapors of the incandescent arc present, then, analogous properties to those of carbon and different from those of the vapors of the alkaline salts.

These properties are those of arcs between pure metals and are explained, I believe, by the sudden cessation of conductivity by transport of the ions at the moment of extinction, and the impossibility of relighting without raising the voltage to a point at which there will be ionization propagated as a discharge from the negative pole. It is thus that I have explained lately[9] the curious dissymmetry of the arcs between metals and carbon. On the other part I have noted that with solid pure carbons, the phenomenon of pro-

8. *Comptes Rendus*, December, 1898, and March, 1899.
9. *Revue générale des Sciences*, 30th July, 1901.

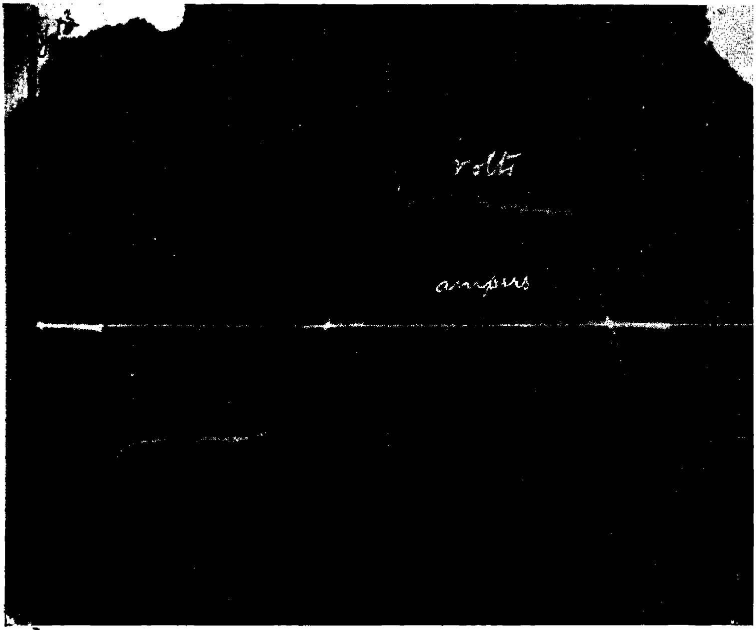


FIG. 8.

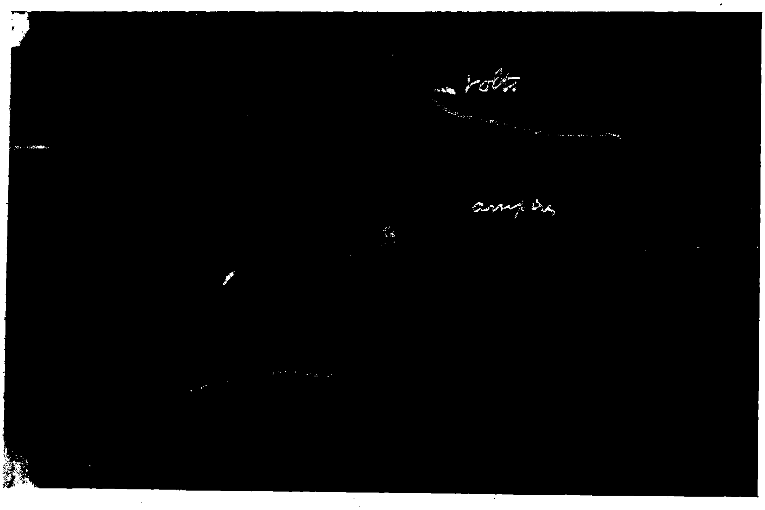


FIG. 9.

longed zero is especially marked, accompanied by small current, as indicated in Fig. 8, which do not permit ionization of other gases between the electrodes. We might, I believe, conclude that this phenomenon is one which characterizes purely ionic conductivity of pure opposed vapors. If the alternating arc between cored carbons of commerce presents on the contrary rounded curves, and acts, as we might say, as a simple dead resistance,[10] the case is very simple, since the conductivity is artificially increased by the addition of salts of sodium and potassium in the cores; the alternating arc between electrodes of pure carbon and with the presence of foreign gases, gives discontinuous phenomena of exactly the same order as those which we have observed with the arc between mercury, and more generally between metals in the open (for mercury is not exceptional from this point of view).

In passing, I desire to point out a bearing which the curve of Fig. 8 offers relative to alternating currents. There is a very bright point, at each relighting, whilst the current remains sensibly nil. There results a very great reduction of the power factor (and not of phase, as has often been said). Again the form of the voltage curve is such that the current produced in the shunt coil of the lamp is smaller than in the case of a current of ordinary sinusoidal form corresponding to the same mean effective voltage. Finally, for the same reason, the length of the arc is often reduced comparatively to that of an ordinary arc. The same effect is produced, however, when a mineralized incandescent arc is fed with rectified current not produced continuously by means of a Pollak or Nodon electric valve; the action ceases to have any relation with that given by a really continuous current.

Theoretical Considerations upon the Arrangement of the Electrodes.

One of the most important questions which follows the employment in electrodes of mineral substances is knowing what role they play in the production of the arc and in what form of electrode they may preferably be introduced. The interest of this question is increased by the fact that very different solutions, some even opposite in character, have been suggested by various inventors. Steinmetz, being inspired by the phenomena of the mercury arc[11] recommends the mineralizing of the cathode. Wedding having

10. *Comptes Rendus,* December, 1899.
11. *Electrical World & Engineer,* 1904, *loc. cit.*

counseled the mineralizing of both electrodes,[12] we find several manufacturers in Germany employing flaming carbons side by side for the two electrodes. For my part, I prefer to concentrate the greater part of the mineral substances in the anode. As has just been seen, each of these dispositions may find theoretical justification and it is for experience to decide which is the best.

Following present ideas as to electrons, it seems reasonable that the arc is formed to carry the ions. For a long time only the carrying of the positive ions from the anode to the cathode has been considered, since these have a greater mass than the negative electrons; they are more visible and the excess of their mass gives place in the arc between carbons to an apparent transport of matter from the positive to the negative pole. I have measured the velocity of this transport and shown that it is of the order of some hundreds of meters per second.[13] More recently Mr. Child[14] has shown by the same method that the cathode emits rays having a still greater velocity of propagation, and which must be attributed to the electrons thrown out from the cathode before the establishment of the current of anodic ions. As we have seen above, there is a sort of initial discharge analogous to a disruptive discharge, and which explains very simply the dissymmetry of the arc between metals and carbon; a metallic electrode having a rate of cooling greater than that of an electrode of carbon, the initial ionization of the cathode can, in fact, only be produced by the application of a voltage great enough to produce a disruptive discharge sufficient to start vaporization at a point.

This phenomena of initial ionization of the cathode is still more easily observable in the arc from mercury, and has been thus studied more completely by Cooper-Hewitt,[15] Weintraub,[16] etc. Sometimes the negative electrons are discharged against the surface of the anode and heated by their repeated shocks; if the temperature which is reached is below the point of volatilization of the anode, the latter plays only a passive role, evidenced by a small loss of voltage at contact. This is the case with the iron anode in the Cooper-Hewitt lamps, having a loss of 2.5 watts as

12. *Elek. Zeit., loc. cit.*, 1902, H. 32.
13. A. Blondel, Recherches sur l'arc electrique (third article), *Lumiére Electrique*, 1891.
14. Child, *Physical Review*, 1900, No. 10, p. 151.
15. *Electrical World & Engineer*, 1902, and Von Recklinghausen, *Elek. Zeit.*, 1902, H. 33.
16. Weintraub, *Phil. Mag.*, 1904.

compared with 5 watts at the cathode. On the other hand, if the anode attains the point of volatilization, as is the case with the arc between two carbons or between mercury, it is vaporized in its turn, throwing out positive ions. The mass of the latter being much larger than that of the electrons, the work done at the surface must be much greater. The fall of potential at the anode and the temperature must be greater than at the cathode, and the surface of volatilization itself is more generally larger.

This circumstance shows, in fact, that the arc between carbons is short and that the vapors of carbon have a very feeble emissive power, the same result being produced as in the ordinary arc between carbons, almost all of the light coming from the crater of the positive electrode. On the contrary, the slight brilliancy (due to the low temperature) of electrodes in mercury, the high emissive power mercury vapor, and the great length of the arc produced in vacuum by the volatilization of the cathode alone, bring out the fact that in the mercury arc the essential role from the point of view of light belongs to the gaseous column, and that a mercury anode of mercury is useless, even disadvantageous practically, since it emits too much mercury vapor, producing in the tube a high pressure which increases the resistance. This increased resistance, first studied by Cooper-Hewitt, might be explained, as Weintraub suggested, by the fact that the molecules of the inert vapor prevent the passage of the ionic molecules traveling at a great velocity. The quantity of the inert vapor is reduced by the employment of a non-volatilisable anode, such as iron, and by a chamber for the condensation of the non-ionized vapor.

The electrons coming from the cathode, of which the mass constitutes only a very small part of the mass of vapor produced, are discharged by contact with the anode, liberating very small masses of matter which served them for support and which are then condensed. This is the theory of M. Weintraub.[17]

17. In reality this cannot be asserted positively, because our knowledge is imperfect as to the ionization of a non-volatilizable electrode. I believe, however, that a part of the atoms of free vapor is positively ionized by contact with the anode, and that the positive ions in this form are carried in their turn toward the cathode as well as the ions produced by volatilization of the mercury anode. This partial ionization of the vapor by contact with the anode of iron is not demonstrated, however, by the fall of the potential of 2½ watts found at the iron anode instead of 8 watts at a mercury anode, for the work thus lost would not suffice for the ionization of the anode and correspond simply for the effect of shock of the electrons upon the anode; the heat being dissipated by conductivity and radiation at the anode.

We are, then, forced to admit that in the electric arc, contrary to the ideas formerly received, it is the cathode which plays the principal role. Certain authors, notably Stark[18] and Steinmetz[19] have concluded also that the volatilization of the cathode is an essential condition of the persistence of the arc, and that the mineral vapors of the arc come exclusively from the cathode. We can thus realize an arc between a volatilized cathode and a fixed inert anode, but not inversely between a volatilized anode and an inert cathode. There is, I believe, a confusion between the state at starting the arc and the permanent state, for I have found that we can maintain the arc perfectly (after it has been started by contact) between a mineralized carbon as anode and a heavy cathode of copper, which does not seem to volatilize at the low temperature of the arc and on which we may see the vapors condense in drops. The photographs of the arc with the upper carbon of the cathode seem, however, often to indicate that volatilization is not necessary at the cathode; that even ionization by contact with the vapors takes place at the anode.

Gunther Schulze[20] has, however, recently shown that the fall of potential at the surface of a cathode of carbon opposite a metallic anode is the same as that of a metallic cathode if it is surrounded with the vapors of the anode, or as that of a pure carbon if it is more distant from the anode. However this may be, the solution reached by Mr. Steinmetz rests upon the following principles:

1). It is the cathode which must be formed of mineralized substances to the exclusion of the anode. He employs magnetite in pressed sticks which are consumed very slowly and give a beautiful white light.

2). All vaporization of the anode is useless, contrary to the ideas held by European manufacturers of mineralized arc lamps, and in consequence should be avoided by the employment of a block of copper capable of dissipating the heat and thereby preserving a low temperature.

This combination is very ingenious and elegant, and will be very advantageous from the point of view of simplicity and length of life, since, as I have shown above, a cathode is used much less quickly than an anode, owing to the small mass of matter necessary

18. Stark "Kenntniss des Lichtbogens," *Annalen der Physik*, 1903, No. 12.

19. C. P. Steinmetz, "The Magnetite Arc Lamp," *Electrical World & Engineer*, March 21, 1904.

20. Gunther Schulze, "Spannungsverlust in Elektrischen Lichtbogen," *Annalen der Physik*, 1903, No. 12.

to carry the electrons and the much lower temperature; but in this case, as in that of arcs between carbons in the free air, the small consumption of electrodes seems to be obtained only at the cost of a reduction in efficiency, for the latter is much inferior as we will show later by the figures of tests of arcs with mineralized anode. (See Table II.)

Quite different ideas have guided the development of my lamp, which results from experiments with mineralized carbons by various methods — photographic, photometric, and study of curves of the electrical conditions, which will be shown below. Experience with the mercury arc shows, it is true, that the volatilization of the cathode and *a fortiori* of the anode of an arc produces in general more vapor than is necessary for the transport of the electrons, but it does not establish that this vapor would be useless if we knew how to bring it to a high temperature at which it would supply light. Now the temperature of a volatilizable anode is higher than that of the cathode of the same composition, and ought then bring the mineralized vapors which escape to a degree of incandescence higher than if, in the same position, it were a cathode. Experiment has completely confirmed this presumption, as the comparative figures of Table I will show.

A mineralized carbon placed below gives as cathode 0.513 watt per decimal candle; as anode 0.147 watt. The same mineralized carbon placed above gives as cathode 0.491 watt per decimal candle; as anode 0.167 watt. This shows that on leaving the anode the mineralized vapors are more brilliant, despite their greater abundance, than when leaving the cathode. We may observe this easily by looking at the arc directly through a piece of blackened glass.

A second condition which influences the mean temperature of the vapors in the arc is the disposition of electrodes with relation to the arc. If we place the mineralized anode above the cathode we will observe that the arc is very brilliant near the anode, but falls off rapidly, since the greater part of the inert mineralized vapors, in place of following the flow of current, are separated from it and rise about the anode under the influence of the ascending current of warm gas, losing their brilliancy. On the other hand, if, contrary to custom, we place the anode below, the inert vapors ascend naturally in the same manner as the arc and give out their heat to the arc, which remains brilliant and clear throughout. We have a true phenomenon of incandescence in such mineralized substances heated by means of the electric arc. I will return later

to the peculiarities of this phenomenon with relation to the quantity of mineralized substance.

This difference between the arc arrangements is easily observed by taking direct observation, and may be clearly seen from photographs, notably those reproduced in Figs. 4 and 5. In order to eliminate the actinic effect of the dark arc which masks in part the real luminous phenomena, a part of the negative has been printed with the interposition of a yellow screen which arrests the more refrangible part of the spectrum. Figs. 4 and 5, which show an arc of 5 amperes with anode above and then below, have been thus taken. In the case of Fig. 3, on the contrary, a blue glass was used, which arrested the complementary rays.

The arrangement of a strongly mineralized anode below a pure cathode, used for the first time in my lamp, produces an increase of the mean intensity of the arc, naturally greater as the arc is longer; while not great with very short arcs, the increase of economy becomes important for long arcs obtained with voltages in the neighborhood of 50, despite the small increase of loss by reflection of rays downward from the reflector which surrounds the arc.[21] A photometric test made with commercial carbons after my patents by the Société Auer, and summed up in Table I, puts this phenomenon clearly in evidence; for with the same carbons, the anode mineralized and the cathode pure, the following efficiencies were obtained: The first column referring to a mineral anode, the second to two mineralized electrodes, and the third to a cathode alone mineralized.

With anode below: 0.147 watt per decimal candle; 0.125; 0.491
With anode above: 0.167 watt per decimal candle; 0.143; 0.513

On the other hand, the curves in Fig. 15, which represent the flux of the light (determined directly by a luminometer in mean hemispherical candle-power) as a function of variable voltage under a constant current of 5 amperes with test carbons containing about 5 per cent of fluoride of calcium added to the mineral mass, show how the superiority of the second solution, curve B, over the first, curve A, progressively increases above 40 volts.

Table I also gives the increase of light which may be obtained by mineralizing the cathode itself, but shows that it is small proportionately to the light gained by the mineralization of the anode.

21. The employment of a restricted combustion chamber surrounding the arc, first used by M. Bremer, may help to increase the temperature; but I have learned that the absorption of light produced by vapors thus retained around the arc diminishes the total economy.

Some difficulties of a practical order result from the slag which forms around the upper electrode, it being troublesome always to obtain practically this supplementary mineralization, as we will see later.

TABLE I.— COMPARISON OF THE EFFICIENCY OF ILLUMINATION OBTAINED WITH DIFFERENT ARRANGEMENTS OF MINERALIZED CARBONS (M) AND PURE CARBONS WITH ORDINARY CORES (P).

Polarity, diameter and nature of the carbons.		Mean amperes and volts.		Electric energy, watts	Mean spherical intensity decimal candles.[1]	Specific consumption watts per decimal candle
Lower.	Upper.	Amperes.	Volts.			
+9 mm (M)	−7 mm (P)	3.03	44.4	134.5	914.6	0 147
−7 " (P)	+9 " (M)	3.09	43.0	132 9	792 2	0 167
−9 " (M)	+7 " (P)	3 14	39.1	122.8	239.4	0.518
−9 " (M)	+9 " (M)	3 05	42.7	130 2	908.0	0 143
+9 " (M)	−9 " (M)	3.11	44.0	136.8	1,090.8	0 125
+7 " (P)	−9 " (M)	2.93	46.0	135.0	273.0	0 491

The phenomena of the anode and the cathode are equally in evidence in photographs of horizontal arcs between horizontal carbons. We see that vapors produced from the mineralized electrode ascend for the greater part; also that they have left the surface, and what remain in the arc diminish its brightness and become brilliant only in the neighborhood of the second electrode, even when that is not mineralized. A brush at a point on the surface indicates a cathodic flux or stream of electrons in the midst of the gaseous mass. If both electrodes are mineralized the arc is more brilliant and the two brushes unite. When we lengthen the arc sufficiently to put this phenomenon in plain evidence we see the cathodic brush take the same form as that of the anodic brush, forming two flames with a narrow base, normal to the electrodes and which rise independently and spread out above, where they meet. They often turn in opposite directions and may not meet at all, in which case the arc goes out. The same appearance of independent flames is presented when we lengthen vertically the arc between two mineralized carbons placed one above the other, and especially when the carbons contain salts of potassium or other salts which favor the formation of long flames.

1. The Hefner unit is only .88 of the French decimal candle. These tests were made with a quality of coated carbon of earlier make than that which is made now by the Société Auer.

This appearance may be explained, I believe, by supposing that, first, the ions and the electrons are projected through inert vapors from each electrode, upon the opposing electrode; one part of them combines where the two currents meet, the others, in a much greater number, run their course and are discharged against the opposing electrodes; second, at the surface of the two electrodes the mineral vapors may become ionized either by the vaporization of the substance of the electrode, or by simple contact when of pure carbon or a metal.

In the Bremer lamp the special arrangement of the electrodes converging toward the lower ends, which has been adopted by its maker in order to permit the falling away of the drops of slag without affecting the arc, is not as favorable, from the point of view of the utilization of vapors, as that of my lamp with the anode below; but it permits, however, of the arc curved by the magnet to follow partially the vapors which leave the anode. The greatest fault from this point of view is that in order to direct the arc, it is necessary to employ a magnetic field which does not act on the inert vapors, and spreads out the ionized vapors fan-like; there results an increase of the surface of the arc, which far from being favorable to economy, reduces greatly the temperature of light-giving substances, and by consequence the illumination produced.

The firm of Siemens Brothers has made some tests on this subject, using a deflecting magnetic field of variable intensity, regulating the length of arc in such a manner that it consumed 405 watts (45 volts and 9 amperes) while the ampere-turns of the electrode magnet varied from 0 to 396, the surface of the arc gradually increased from 225 to 369 cm^2, its intrinsic brightness decreased gradually from 9.62 to 3.35 hefner units per mm^2, and the specific consumption rose from 0.187 to 0.328 watt per hefner, figures below those of my lamp given above, despite the greater consumption of energy.

I have noted also analogous variations with a mineralized vertical arc put in rotation by a magnetic field. The employment of a magnetic directing field is then useless, and we should, on the contrary, seek to concentrate the arc in the highest possible degree, notably by increasing the degree of mineralization, as we shall see.

The Influence of the Constitution and the Degree of Mineralization, of Electrodes.

It is very important to elucidate the influence of the degree of mineralization of the electrodes, not only to obtain the maximum luminous economy for a given consumption and life, but also to know whether to incorporate the mineral substances in the paste forming the principal body of the electrode, as in the electrodes of Bremer and those of the author,[22] or in cores of small diameter in the body of the paste. The first process permits of the introduction into the arc of quantities of the mineral substances as large as we may desire, even to 60 or 70 per cent, being limited only by the increase in fragility of the carbons which results, and (for carbons of the Bremer type) only by the excessive production of mineral slag. On the contrary, it is easy to see that the second process permits the introduction of only small quantities of the mineral substances because of the small diameter of the core in the "flaming" carbons, such as those of Siemens or Conradty, for example, 2 to 3 mm for carbons of 9 to 10 mm in diameter is only a small fraction of the total diameter. In admitting that the maximum diameter of the core may be one-third of the diameter of the carbon, the mass of the core is only about one-tenth of the total mass, since the density is generally lower because of its powdered state. As we cannot put in the core material more than 60 to 75 per cent of the mineralized substances, these latter will not be in the mass of carbon in greater proportion than 8 per cent or at the best 10 per cent, if we might force the diameter of the core. If we take account besides of the fact that part of the carbon envelope is burning in place of serving for the formation of the arc, we must then admit that the arc cannot contain more than 15 per cent of mineral substances, as referred to the carbon vapor.

The proportion is limited to a figure still smaller by the scorification, if we employ it in ordinary lamps with vertical electrodes mineralized throughout the mass: in fact, following the results of Professor Wedding,[23] the scorification becomes troublesome in these lamps when there is more than 7 per cent of fluoride of calcium in the two carbons or 14 per cent in the positive carbon

22. My carbons act in burning like those of Bremer, from the point of view of mineralization, for envelopes of pure carbon are proportioned in such a manner as to burn a little shorter than the mineralized body, and the arc is maintained between the latter alone, as if there were no envelope, being thus distinguished from carbons with cores.

23. *Elek Zeit.*, loc. cit.

alone. It is for this reason that M. Bremer, having noted with a sagacity which is to be praised, the usefulness of a higher mineralization has thrown out the ordinary arrangement of carbons and adopted the converging arrangement; but the other German experimenters do not seem to admit this usefulness. According to the researches of Dr. Wedding,[24] the economy is not correspondingly increased when the mineralization goes beyond 15 per cent in the Bremer lamp and 7 per cent in lamps with the carbons placed one above the other, to compensate for the inconvenience of the increase of slag and of smoke. Makers have, therefore, concluded that it is sufficient to introduce this quantity of mineral matter in the usual manner in the core and to avoid thus the formation of slag. Certain specialists[25] claim even that it does not help the economy to go beyond a proportion of 15 to 20 per cent, for too active volatization tends to lower the temperature and, therefore, the degree of incandescence; this opinion must come from the fact that they only know arcs in which the incandescent part of the carbons performs the principal role in the production of light (65 per cent according to Vogel, 75 per cent according to Wedding). But in reality, despite this view, the increasing influence of the arc with mineralization is established by experiment, as shown by Table II, in which we see that the strongly mineralized carbons of Bremer and others give specific economies almost three times those of the lamps with flaming carbons of Siemens & Halske or the Allgemeine Electricitäts Gesellschaft. This difference comes, as we may determine by direct observations or by the accompanying photographic views, that the base of the arc from a highly mineralized anode is more contracted than that of cored or mineralized carbons, and, therefore, gives a very much more intense light. Moreover, the flaming carbons have an evident defect in principle; the core occupies only a small part of the section of the carbon, and it is necessary for the carbon to burn uniformly and the core not be emptied, to realize the best densities of current, which leads to a very rapid use. For example, a lamp of 8 amperes and 40 volts uses from 15 to 17 mm per hour with ordinary carbons, and 27½ mm with flaming carbons with a mineralized core. On the other hand, the enlargement of the crater around the core which the flaming arc produces gives simply an

24. Loc. cit.
25. Otto Vogel, Intensiv Bogenlicht. Zeitschrift für Beleuchtungswesen, 30 Mai, 1903.

Table II.—Candle-Power and Consumption at 110 Volts.

I. Direct Current.

Type of lamp.	Amperes.	Volts.	Watts. Useful	Watts. Total.	Mean hemispherical c. p.	Specific consumption. Absolute	Specific consumption. Practical at 110 volts.	Hourly consumption min electrode. mm
Ordinary lamp, pure carbons[1]	9	40	360	495	700	0.514	......	16–17
Ordinary lamp, pure carbons[1]	9	35	315	330	540	0.583	......	16–17
Flaming arc, vertical carbons[1]	9	40	360	495	910	0.396	......	27.5
Flaming arc, converging carbons[1]	9	45	405	495	2,000	0.202	......	34–42.5
Enclosed arc, American[4]	6.8	70	476	768	329	1.45	2.334	1.5–2
Enclosed arc, Steinmetz	3.5	91	320	385	400?	0.800	0.962	1–2
Bremer lamp (9 amp)[2].	9	48	412	495	4,814	0.131	0.143	35–45
Blondel lamp (9 amp)[7].	9.1	43	391.3	500	4,800	0.081	......	....
Blondel lamp (5 amp)[3].	5.12	51.6	241.2	282	2,210	0.109	......	16–17
Blondel lamp (3 amp)[3]	2.99	57.4	171.5	165	1,339	0.128	......	16–17
Blondel, 3 in series, (5 amp)[7]	5	30	150	180	1,250	0.120	0.144	15–16
Blondel, enclosed (3 amp)	3	60	180	330	700	0.257	0.471	3–5
Blondel, 2 in series	3	45	135	165	500	0.270	0.330	3–5

II. Alternating Current.

Type of lamp.	Amperes.	Volts.	Watts. Useful	Watts. Total.	Mean hemispherical c. p.	Specific consumption. Absolute	Specific consumption. Practical at 110 volts.	Hourly consumption min electrode. mm
Ordinary lamp, non-min carbons	9	30	270	330	350	0.772	......	....
Ordinary lamp, cored carbons[6]	15	35	480	555	470	1.02	......	15–16
Flaming arc, vertical carbons	9	30	270	330	700	0.386	......	30
Flaming arc, converging carbons	9	45	405	495	2,000	0.202	.....	35–45
Enclosed arc[4]	6.6	70	482	726	314	1.535	2.312	1–2
Bremer lamp[5]	9	48	....	...	...	0.131	0.143	35–45
Blondel lamp[6]	10	35	255	370	1,890	0.135	0.174	15–16
Blondel lamp	5	27	135	185	600	0.225	0.308	15–16

1. Lecture by M. Zeidler, Engineer of Allgemeine Elektricitäts Gesellschaft before the Elektrotechnischer Verein de Berlin, 23d Dec., 1902.
2. M. W. Beigon von Czudnochowski, *Verhand.* der Deutschen Physikalischen Gesellschaft, 1903, No. 7. These figures relate to commercial carbons of large diameter, instead of from 7 to 8 mm, in the case of the lamps tested by M. Wedding, of which the consumption was excessive in comparison with other lamps.
3. Tests of Prof. Wedding.
4. Tests of Prof. Matthews, second report, N. E. L. A., pp. 30–32, and third report, p. 17. These figures are more favorable than those of European experimenters.
5. Estimated from the comparison made by Prof. Wedding (loc. cit.), who found the same efficiency for the two kinds of currents.
6. Tests made in the Laboratoire Central d'Electricite, Paris.
7. Tests made in the Laboratoire de la Société Auer, Paris.

arc between pure carbons in which is introduced centrally a small quantity of mineral substances. This suffices to furnish in the arc ionizing vapors to transport the current and thus produce a very long arc, but not to concentrate it and render it more brilliant. In fact, it results from the researches which I have made during the last few years on this subject, that the quantity of the ionized vapor is only a very small part of the total vapor in the arc, as I have shown above, by the separation of the mixed ascending vapors. The influence of mineralization upon the length of the

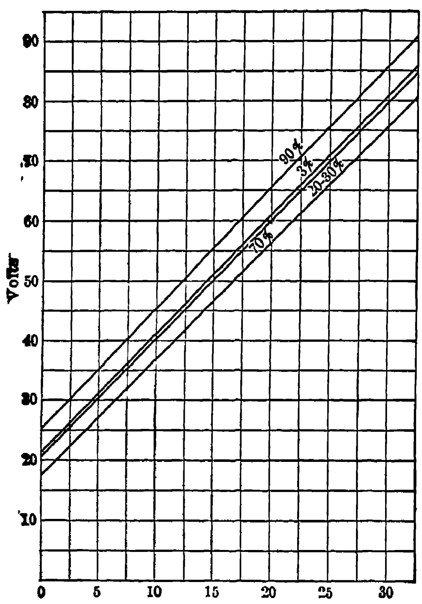


Fig. 10.

arc is still better shown by means of the curves of voltage in the function of the length, taken from electrodes supplied with constant current. In comparing the results obtained from a series of measurements made of carbons containing increasing proportions of fluor-spar, represented by the curves of Fig. 10,[26] which are straight lines (as are those of Mrs. Ayrton relative to the arc between pure carbons), we may easily see that:

26. These curves are from a large number of readings, often little concordant owing to the greater or less accumulation of scoria at the surface, and the difference in quality of the fluxes used. They, therefore, have only a relative value.

1). These straight lines have various inclinations, according to the mineralization, which correspond to the varying conducting power of the gaseous arc.

2). The ordinates at the origin represent the losses in volts by the passage of current through the electrodes, which diminish with the mineralization. We see thus that the apparent conducting power of the arc increases at first very quickly with the mineralization to a maximum in the neighborhood of 20 to 30 per cent of fluor-spar, then decreases slowly, leading to the paradoxical result that the increase of conducting substances diminishes the conducting power. This proves in fact that the conducting power is due to the transport of the ions; the ions of mineral vapor being more volatile than those of carbon, volatilize before them while ionizing, and require a smaller expenditure energy of ionization at the surface of the electrodes; but when the quantity of ionized vapor is sufficient to carry the whole current, the addition of mineralization produces (as in the mercury arc) inert vapors, of which the molecules block the free path of the ions. The increased shocks of the latter act to increase the apparent resistance and the heating in the gaseous arc. Thus for equal voltages with carbon electrodes we should find, as experiment shows, that the shortest arc is the most brilliant. The quantity of vapors thrown out per unit of surface increases, the same is true of the number of ions, and the base of the arc contracts, this adding a new cause of concentration of the light.

At this limit, that is to say, if there is no longer carbon in the electrodes, but pure fluor-spar (a condition which the low fusing point will not permit us to practically reach) we would see a very steep straight line, analogous to that obtained by Rasch[27] (with alternating currents unhappily) using electrodes formed of metallic oxides. But while the increase of economy with the mineralization becomes more and more slow, the loss of energy due to the resistance of the electrodes themselves and the loss of light produced by interference of the electrodes keep on increasing, and also the practical difficulties of striking the arc and of getting rid of the slag and vapor deposits; it thus does not seem advisable, for the moment at least, to go beyond 60 per cent as the degree of mineralization (in the particular case of the fluor-spar).

27. E. Rasch, "Ein neues Verfahren für Erzeugung von Electrischem Licht," *Elek. Zeit.*, 1901, p 156.

As to the carbon of composite electrodes, it can be considered as having the following functions in the electrodes.

1). It gives to the latter the necessary conducting power when cold (the mineral substances employed are generally insulators when cold) in order to lead the current to each point of a section; this condition is not realized with electrodes of pure oxides, and we have tried without success up to the present time to add them to other conducting bodies than carbon.

2). To prevent the fusion of the electrodes in the neighborhood of their points, which occurs quickly in the absence of carbon, for the substances most advantageous, such as fluoride of calcium, are fusible and volatile below 1000 deg. Centigrade. These difficulties have prevented the employment of pure oxides made conducting when cold by the addition of other mineral substances. Mr. Steinmetz has been able to use the oxide of iron for the reason that it is a conductor by itself, and he had been able to inclose it in a tube of iron which oxidizes little by little (playing the same role as the carbon envelope in the author's coated carbons).

3). It may aid (in the case of slightly mineralized electrodes) the conductivity of the gaseous arc in volatilizing and ionizing at the surface of the electrodes at the same time as the mineral substances; but with the very mineralized electrodes I have employed, the carbon burns little by little (without volatilizing) at the surface of the electrodes in presence of oxygen, and the mineral substances alone furnish the ionized vapors. In fact, on the one hand, the abundant distillation of the vapors from mineral substances with low points of vaporization does not permit of the surface of the electrodes rising to a temperature sufficient for the volatilization of the carbon; on the other hand, the surface appears covered with a layer of melted mineral substances; finally, the great reduction, shown by a fall of potential, corresponding to work done by the volatilization (20 to 25 volts), tends to confirm the belief that the mineral substances are alone volatilized. Perhaps, however, they there may be mechanically carried along atoms of carbon carrying electric charges. This point has not yet been elucidated, and should be made the subject of an interesting study.

The envelope of carbon around the electrodes does not take part in the production of the arc and serves particularly to prevent the lateral oxidation of the body of the mineralized carbon which leads to scorification, and thus increases the life of the electrodes.

But it plays another important part from the point of view of conductivity, for it has a section nearly equal to that of the mineralized body which it surrounds, the specific resistance of which is considerable. The envelope thus serves principally to conduct the current, and it is very necessary that it be in perfect contact with the mineralized body over the whole of its length. For this reason it is preferable to compress it around the composite electrode in the course of manufacture before firing, than apply it afterward to the mineralized carbon, for in the last case, not only is the contact very bad, but during the firing and in course of combustion, mineral matter will rise to the surface of the mineralized body and form an insulating bed between it and the envelope.

RESULTS OBTAINED.

The lamps of Bremer and those with the flaming arc, are already well known; those of the author's system have only been manufactured for a short time. In order to permit of a comparison of the various systems, I have given in Table II the principal data I have been able to collect upon the specific consumption of energy and upon the actual rate of usage of electrodes, employing as much as possible the results of other experimenters in order to give as impartial figures as possible. The luminous intensity of the Steinmetz lamp with direct currents is presumably 400 candles by comparison with the ordinary arcs, according to the figures of Mr. Willis Holmes.[28] I am not aware that Mr. Steinmetz has constructed a lamp for alternating currents.

We remark at once the enormous superiority in economy of mineralized arc lamps over all the others, and particularly of the Bremer lamps with converging carbons, and that of the author. The two last lamps give practically the same economy with alternating current, without doubt because the carbons of M. Bremer in this case are somewhat more mineralized. On the contrary, with direct currents, the lamp of the author has for equal currents the advantage. As the current diminishes, the economy of the arc is rapidly reduced, from which follows the smaller economy of the lamps of the author at lower amperage; for the same current of three amperes the present Bremer lamp would give an economy much less if it would work at that amperage, but at the present time there are no 3-amp. Bremer lamps.

28. ***Electrical World & Engineer*, May 28, 1904, p. 1053.**

Aside from the question of economy, it is interesting to compare the lamps of the author with the lamps having converging carbons. The first present over the second the following advantages:

1). The mechanism is more simple, and has no special arrangements for starting.

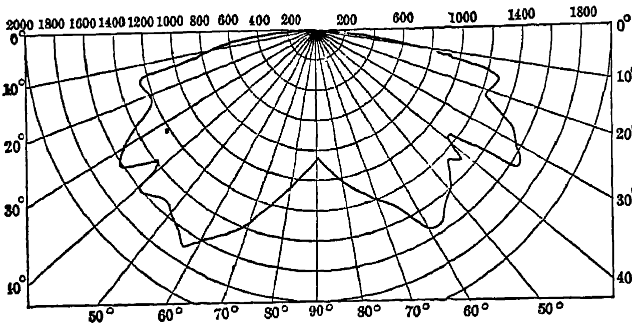


FIG. 11.

2). The lamps with converging carbons give a very odd distribution of light, most powerful in the plane perpendicular to the carbons and concentrated beneath the lamp, which might be advantageous for the lighting of rooms but not for public lighting.

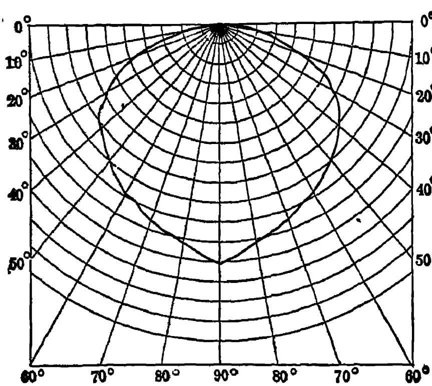


FIG. 12.

It suffices to take account of the results obtained by Professor Wedding of the two types of lamp reproduced in Figs. 11 and 12. The lamp of the author admits of sending the light more horizontally, if we wish it, without lowering or extending the luminous point below the condenser. We may regulate this height at will very

simply, by varying the diameter of the upper carbon; for the reduction of work is greater, and in consequence, the possible travel with the upper carbon will be shorter, when the arc is nearer the condenser which incloses it. Finally the lamps with converging carbons give more light in the direction perpendicular to the plane of the carbons than in their plane; on the contrary, carbons placed one above the other give the same light all around them.

3). The electrodes burn more evenly and with less variation of color or of luminous intensity in the lamps of the author than in the lamps with converging carbons. In fact, the arc plays upon the surface of the point of the lower electrode in such a manner as to use it up equally (as in Marks' lamp) without change of length of arc; whilst the arc can play successively between various points of the ends of converging electrodes without change of length, a change which causes variation in intensity and color. This fault is still more grave with cored flaming carbons than with the Bremer carbons, since if the arc quits the core and plays upon the pure carbon, the current falls, mineralization no longer takes place, and the arc fails to give light; this state is produced particularly when the magnetic field is excited in series, since then the current being diminished is no longer strong enough to direct the arc.

The disposition of the converging carbons is thus vicious in principle. In order to remedy this, M. Bremer and his imitators have been forced to the employment of very thin carbons which give rise to the following troubles:

4). The consumption and the electric resistance of mineralized carbons in the lamp with converging electrodes are excessive as indicated in the table; the consumption is double or triple that of the ordinary carbons, and this forces the employment either of long carbons, from 400 to 500 mm or even longer, or the multiple lamp, having a set of mechanisms for each pair of independent carbons. All these solutions complicate, without helping, the problem. On the contrary, in my lamp, where the arc is free to be moved over the surface of the electrode which remains nearly flat, the diameter may be much increased and the consumption does not exceed that of a lamp with ordinary carbons.

At the same time the electrical resistance per unit of length becomes less. The solid mineralized carbons have, in fact, a specific resistance, double or triple that of ordinary pure carbons; the same is true of the resistance of the very thin pure carbons of the flaming lamps. In the German lamps with long electrodes,

the drop is from 5 to 8 volts in the electrodes for a lamp with direct current, and double that for an alternating current lamp, which figures are reduced one-half for the mineralized carbons with thin envelopes.[29]

The question of the consumption of substances mixed with mineralized substances raises some remarkable and interesting theories. We are led to believe that consumption, in fact, increases on the one hand with the degree of mineralization, and on the other hand with the facilities for oxidation, which appears a contradiction; it is much greater with the electrodes of pure mineral matters of Steinmetz and Rasch. These phenomena can be explained by the part that the carbon plays in the mixture, being more refractory and adding to the conductivity; if the carbon is abundant, the surface of the electrode is sufficiently conducting to admit of the base of the arc being large, and is covered only with a thin layer of melted mineral substance; then the volatization is little active; when the heat diminishes (either by the addition of a larger proportion of material or by oxidation) the surface of the electrode is less conductive and is covered by a thicker layer of mineral matter in fusion. The base of the arc then becomes more concentrated, the vaporization becomes more active, and the carbon is consumed faster. We see then that the consumption of the carbon and the luminous efficiency vary in the same sense; they increase together, for example, with the density of the current, with the size of the carbons, with the greater or less amount of air admitted through the shutter in the globe, etc. If we inclose the arc in a vessel, closed or nearly closed (always taking care to dispose of the smoke and ashes as soon as they are formed), the oxidation being reduced, the same is true of the carbon, which may fall from 2 to 4 mm instead of from 15 to 16 mm in the free air; the slag is formed in smaller quantities, and we may greatly reduce the thickness of the envelope, which, however, remains always advantageous through increasing the conducting power. A life of 100 hours may then be obtained by the mineral inclosed arc, without having the electrodes of an exaggerated length (320 to 400 mm). Here in Europe, the inclosed arc with ordinary carbons is employed but rarely, because of the lower price of labor

29. I will add in passing that this thin envelope may, however, be useful even in the lamps with converging carbons in permitting the relighting of the carbons by lateral contact, which the slag renders difficult with the Bremer lamps.

and the high price of electrical energy. For this reason the mineralized inclosed arc does not appeal to Europeans.

4). The Bremer lamp and *a fortiori* the flaming lamps do not permit of the employment of currents as low as in the case of lamps with cored carbons placed vertically; while the minimum current up to recently is from 8 to 10 amperes for the flaming lamps and from 6 to 10 amperes for the Bremer lamps, the manufacturers of the author's lamp have placed on the market a lamp of 3 amperes, and even Mr. Proskey has been able to make his lamp burn very nicely with from ½ to 2 amperes, always attaining an economy better than that of the ordinary lamps of the same rating. This is one of the great commercial advantages (as Mr. Wedding has shown in a report) of the new solution as against the old.

I hope that the results which I have given here will interest electrical engineers and will contribute to justify, from a practical point of view, the new type of carbons and lamps which I have endeavored to present from the theoretical point of view, and to make known the details of their working.

I hope that the freedom with which I have made the presentation, without reserving anything, will win for me in every case the good will of my readers.

Discussion.

Chairman Lieb: Gentlemen, you have heard these two papers — that of Dr. Steinmetz and the paper of Prof. Blondel just read. In introducing the discussion, I will make just a few remarks. Prof. Blondel's carbon is really a concentrically cored carbon; that is, it has two cores, one within the other. I have had opportunity of seeing a number of practical tests made with lamps equipped with these carbons, and the illuminating effects were certainly remarkable. A Blondel lamp using three amperes direct current was hung up in the street in place of a 450-watt, 5½-ampere, direct-current enclosed arc lamp, the lamps being lighted alternately to observe the effective illumination of the street. As far as effective illumination in the street was concerned there could be no doubt that the Blondel lamp was the more effective. The reflector, which is shown in an illustration in Prof. Blondel's paper, becomes effective, improving the distribution, as the underside of it becomes coated with the white oxides, making an efficient reflecting surface.

Prof. J. P. Jackson: I wish more particularly to speak of the practical use of the Steinmetz luminous arc. This year I have been under especially advantageous conditions for obtaining data as to how well or how poorly the luminous arc would work under commercial conditions. In the city of Harrisburg, Pa., a plant of twenty-five lights was installed by the General Electric Company, all using the present luminous arc, for com-

parison with two types which the commercial company lighting the city then had in use; the first being the ordinary 9.6-amperes, 480-watt open carbon arc, and the second being the ordinary 450 or 480-watt enclosed direct-current arc. It is a little difficult, of course, as anybody who deals with light knows, to get a fair determination of the actual values of light. In order to get some idea, however, of the value of the relative illumination of the luminous arc which was there for at least six months — although I must confess it was under the attention of an expert, and therefore had a little advantage over the other arcs — in order to get a fair comparison, we took what some of the companies called an illuminometer, which is nothing more or less than a black box with type inside of it, suitably arranged for looking in and getting the size of type, or the distance away from the light that you can read the type. We compared the luminous arc of Dr. Steinmetz under these conditions out on the streets with something like twenty or thirty enclosed arcs, and about an equal number of open arcs, of the capacity of which I have spoken. We found in every case that the luminous arc gave us a reading on every size of type, gave us a reading illumination from 20 to 30 per cent further than could be obtained with the ordinary carbon electrode lamps. Moreover, the luminous arc was using at the time approximately 320-watts, against 480 of the ordinary electrode arcs.

In order to determine still further the relative value of the two lamps, in order that a decision could be made as to what lamp should be used in that particular city, one of these lamps was taken to the Pennsylvania State College, where I have my dwelling, and put upon a photometer bar, was worked against a standardized incandescent lamp; the horizontal and angular candle powers were taken very carefully, and a whole day was spent in measuring them, and then the same men, same instruments, same standards and all other conditions exactly the same, were used in getting the candle power of the 9.6-ampere open-arc lamp of the carbon electrode type. Now, although you cannot compare an arc lamp with an incandescent standard with any satisfaction, I feel that, putting the two lamps in the same bar, with the same instruments and the same observers, we got a fair comparison, and I may say that though the Brush arc gave a much greater illumination at forty-five degree angle beam, and beams near that angle, the luminous arc of Dr. Steinmetz gave a perceptibly larger illumination near the horizontal, much more spherical illumination, and for street lighting was more satisfactory. In other words, the experiment on the photometer bar fully bore out the experiment on the streets, that the illumination from the luminous arc, although possibly not so brilliant in the forty-five degree circle around the arc, was better at distances.

Dr. Clayton H. Sharp: I think every one who is interested in lighting is very much indebted to Dr. Steinmetz for the extremely lucid presentation which he has given us in his valuable thesis on the mechanism of the arc. I feel that personally I have learned a very great deal and that my ideas as to the actual process which goes on in the arc have been made very much clearer by listening to Dr. Steinmetz's paper.

There seems, however, to be some discrepancy between the views of Dr. Steinmetz and of Prof. Blondel. Dr. Steinmetz considers a blast passing out

from the cathode and constituting the heated stream to which the luminosity of the luminous arc is due, while Prof. Blondel assumes a stream of ions to pass from both electrodes and convey the current from the one to the other. The divergent views which these writers have presented lead to different conclusions as to the proper arrangement of the impregnated electrode, the electrode which gives rise to the luminous vapor in the arc. Which of these gentlemen is correct is probably a question that will have to be determined by further experiment and consideration of the matter.

There is no question as to the very high luminous efficiency obtained in the Blondel lamp. The figures which are given in this table refer to a lamp of relatively large current capacity, that is, to a 9-ampere lamp. I have made some experiments with a lamp of three amperes only. This lamp gave a very high candle-power at very small watts consumption. The resultant value for the watts per mean lower hemispherical candle-power came out 0.16 to 0.18. In other words, the specific consumption of this lamp, measured in watts per mean lower hemispherical candle-power, was somewhere below 0.2, whereas the ordinary open arc-light of the best type requires in the neighborhood of ¾ of a watt per mean lower hemispherical candle-power, and as we all know, the ordinary enclosed arc considerably more.

Prof. E. L. Nichols I take this opportunity to say a word with reference to the state of affairs which we are about to meet in photometry, in consequence of the introduction of these new factors arising from selective radiation. The difficulties of making fair comparisons of the ordinary old-fashioned open-arc lamp, with nothing but carbon to deal with, where the light came chiefly from the terminals of the carbon, were sufficiently great. We have now injected into the art, and it seems to me it will soon be of commercial as well as scientific interest, these various new forms of light in which the radiation is highly selective. When it comes to the question of comparison, for example, of the relative merits of a flaming arc of this tpye, in which the calcium lines are the chief source of light, and the mercury arc with its bright line spectrum, we are confronted by a new problem. The photometrician has got to go over from the mere comparison of light for light, which in the case of these new lights becomes an impossibility to the study of the spectrum; and it seems to me that the introduction upon the market of lights such as we are now coming to means that we have got to reject the plain old-fashioned photometry, and take up with spectro-photometry, which is quite a different matter.

I mention this matter right here for the purpose of saying, that while I do not know the manner in which these measurements were made, it is my idea that all that they can be considered as expressing, if justly interpreted at the present moment, is that the primary arc is a very powerful source of light. I do not think you can put anything more definite upon the data in the way of an interpretation, in spite of the fact that the figures run to four places of decimals. There are four significant figures, but I do not think that the result is more than qualitative. Now the development of practical methods for the balancing up against one another of

these diverse sources of light appears to me the most difficult problem with which the photometrist has ever been confronted. The ordinary photometry of light from incandescent carbon is an exceedingly simply matter compared with it. I hope that the photometrician who has to deal with these problems in commercial aspects will not evade or slight this problem, but that he will grasp it and solve it and will provide the producer and consumer of light with some rational system by means of which we can know what we are dealing with At the present moment I must content myself with expressing the opinion that the photometry, in any strict sense of the word, of these newer light sources, is non-existent.

Prof. JACKSON: May I make a remark along certain lines which Prof. Nichol's remarks covered to some extent. We are going to use the luminous arcs and decide whether we want them or do not want them, and if the luminous arc will enable a man to see a stone in the street, which is in his way, and it will enable him to see that and avoid it, better than the ordinary arc light will, I will say, from a commercial point of view, that that is the best lamp, and I will say, in answer to Prof. Nichols's remarks, that that is the way I try to carry on the practical experiments which I tried to explain.

Dr. C. P. STEINMETZ: I believe I can explain in a few words the apparent discrepancy between Dr. Blondel's results and mine. The explanation is found in the words "impregnated carbons" or "mineralized carbons." That is, all the arcs with which Dr. Blondel experimented were carbon arcs made luminous by evaporation. There are three methods of using arcs for illumination, as stated in my paper, of which I consider, at least for the conditions existing in the United States, the third one to be preferable, the object being to combine very high efficiency with long life. This class, however, the electroluminous arcs, has not been given any consideration in Prof. Blondel's paper. Apparently he has been deterred by the great practical difficulty resulting from the flicker due to the negative running spot which had to be overcome before such arcs could be commercially successful. All Dr. Blondel's arcs were carbon arcs, and therefore, as he stated, follow the laws of the carbon arc. The anode, being the hotter terminal, is the one which has to be impregnated to get the highest efficiency of the flaming arc. That can very nicely be illustrated by making photometric tests with the four kinds of flame carbons, which are impregnated with calcium, strontium, barium and magnesium compounds, respectively, by using them as positive, with a plain carbon as negative, and then as negative with plain carbon positive. In all cases the calcium gives the highest efficiency, but the relative proportions are entirely different. Using positive impregnated carbons, the proportion is about that of the volatility of the compounds; as negative the results are considerably different, and the magnesium changes its position in the series, being less efficient as positive and more efficient as negative.

With the efficiency, however, I have not dealt in my paper at all, because that is a feature which my results lead me to believe depends rather more on the material which is introduced in the arc stream, than on the methods of introducing it, whether from the positive by evaporation, accompanied by

relatively rapid consumption, or from the negative by electroconduction, at a slower rate. But amongst all the chemical elements there seem to be really only three groups of high efficiency: the mercury, the calcium group, and the iron group. It is the latter group which I prefer, since it gives white light, a long life, and the highest luminous efficiency.

Regarding the efficiency of the magnetic arc, given in Dr. Blondel's paper, the values are far below those reached by the modern "magnetite" arc. The reason is, that iron and not magnetite is now the most efficient member of the iron group, and therefore is not used pure, as it probably was in Dr. Blondel's test. The most efficient arc which we ever observed was a 500-watt arc, which gave an efficiency of about 0.15-watt per mean spherical British candle, that is about twenty-five times the efficiency of the incandescent lamp, and far higher than any flame carbon I ever observed. But this arc is not at present suitable for commercial use. It had a slow burning electrode. The consideration of these two different characteristics, the feeding of the arc stream from the negative by electroconduction and from the positive by evaporation, will explain immediately the discrepancies in the conclusions of Dr. Blondel, who investigated only the one feature, and the conclusions I arrived at by considering both methods of producing the luminous arc flame.

CHAIRMAN LIEB: We are now awaited by Section B, and when we get through the discussion of Col. Crompton's paper, we will take up the papers of Dr. Nichols and Prof. Lombardi.

JOINT SESSION OF SECTIONS B AND E.

Chairman Steinmetz, of Section B, called the meeting to order at 10:30 o'clock. Col. Crompton then presented his paper, as follows:

STANDARDIZATION OF DYNAMO-ELECTRIC MACHINERY AND APPARATUS.

BY COL. R. E. B. CROMPTON, *Delegate of the Institution of Electrical Engineers.*

Movement in England in Favor of Standardizing.

The standardizing of materials and machinery used by engineers has already made considerable progress in America. In England a strong and representative committee was appointed by the Council of the Civil Engineers about three years ago at the suggestion of Sir John Wolfe Barry originally to standardize rolled iron and steel sections, but this led to the formation of other committees to deal with the standardizing of all classes of machinery and parts used by engineers wherever such standardizing seemed to be necessary or advantageous to manufacturers and users.

Subdivision of Electrical Matter.

The committee appointed to deal with electrical questions after a few preliminary sittings decided to divide their subject as follows, and appointed subcommittees to deal with them:

1. Cables and conduits.
2. Telegraphs and telephones.
3. Electrical generators, including the prime movers that drive them, motors and transformers.
4. Materials used in tramway construction.
5. The determination of certain physical constants particularly those relating to temperatures and methods of determining the same.

Work already Carried out.

These subcommittees, which really became the working committees dealing with electrical questions, have now been at work for two years. That which dealt with cables has completed and issued a very complete report and recommendations. That dealing with tramway material has reported on part of the material they use. (Appendix D.) The third, dealing with the more complex subject of dynamo-electric machinery, of which I had the honor to

be elected as chairman, has had many sittings, and has recently issued an interim report.

Work Remaining Unfinished.

The recommendations and definitions decided on in this report are printed in their complete form as an appendix to this paper (Appendix A), that is to say as far as the work of the committee has gone up to the present time. One or two important subjects have not yet been finally reported on. These relate to transformers, standard test conditions and to the allowable variations from the adopted standards.

During the early stages of our work we were helped by the labors of the committees which sat previously in America and Germany to deal with the same subject, and we feel that it might assist those who are interested in the matter if some description of our work was laid before this Congress in the hopes that any discussion that follows on this paper may be of service to all of us engaged in this interesting subject.

Extent to Which Electrical Standards can be usefully Carried.

I think we must all agree that electrical standardization must bear a different meaning to standardization of the far older and more crystallized types of machinery used by mechanical engineers. It is highly undesirable that any types, patterns or sizes should be standardized if these are likely in any way to hinder the future development of design, but all who have looked into the matter know how much useful electrical standardizing can be carried out in such matters as the settling on correct nomenclature, and definitions of certain terms hitherto used in a somewhat loose way in text-books or in trade lists, in settling standard test conditions, in determining a satisfactory method of measuring the rise of temperatures in the parts of electrical machinery that are affected by temperature rise. In addition to these we all feel that some attempt must be made to standardize sizes in order, if possible, to reduce the number of patterns that now must be kept by manufacturers and many of which are felt by them to be wholly unnecessary, and which are only demanded because some manufacturers have produced them for special purposes.

Standard Lists.

It appears desirable that in place of these many patterns a standard list of a sufficient number of sizes to fill the ordinary

requirements of users should be laid down, that these sizes should be so marked and their output under various working conditions should be so clearly defined that any purchaser of a standard machine should always be able by referring to his table of standard conditions to determine with accuracy exactly what the manufacturer guarantees when he attaches the standard mark to each standard machine.

Procedure of the English Committees.

It may be convenient at this stage to explain the procedure by which our committee has obtained the views of manufacturers, consulting engineers and users on all the debatable points which they have met with. The committee itself, being very representative, was able to draw up a list of the questions which appeared likely to arise and to circulate these in the form of a circular, which in our case we marked "C. L. 36" (Appendix B), and on which we invited remarks and criticism. This circular was sent out to the whole trade and to most of the consulting engineers and to a selected number of the principal users. After the replies were received and tabulated, they were discussed in the committee, which was then in a position to see that certain points were practically accepted by every one. The same circular was then reissued marked "C. L. 36A" (Appendix C), calling attention to other points remaining unsettled. By the successive issues of this amended circular considerable progress was made without the necessity and loss of time which would have followed if we had held conferences to decide on all these minor points, but when all that was possible had been done by correspondence it became necessary to hold a conference to decide on the matters which remained unsettled. At this conference every one who held strong views on these questions was invited to speak, and the matters were voted upon and final decisions were thus arrived at.

Standard Electrical Pressures — Low Pressures.

The first question we attacked was the very serious difficulty which has arisen in England owing to the multiplicity of electrical pressures or voltages used. The first electrical pressure measured at the consumers' terminals which can in any way be called a standard pressure was that adopted throughout London and other large towns of 100 volts. This was adopted because, at that time, the electrical energy generally used for lighting 100-volt lamps

was on the whole the most trustworthy and suitable to the users' requirements. These 100-volt lamps were, as a rule, supplied from three-wire systems, supplied with 200 volts across the outers, and in a few cases from five-wire systems having 400 volts across the outers. As the lamp manufacture improved, other towns successively adopted 105, 110, 115 up to 130 volts at the consumers' terminals, but as soon as trustworthy lamps in excess of 200 volts were produced many towns doubled their pressure, supplying their customers for a time from the original outer conductors and eventually resumed the three-wire pressure at the outers at double the original, that is to say, from 400 up to 500 volts. This great range of pressures in use made it extremely difficult to draw up a list of standard plant, which would serve the majority of these pressures. We, therefore, finally decided to fix on standard pressures which, with a 10 per cent variation on either side of them would fit most of the existing voltages. We, therefore, fixed on 110 volts which, with the above margin, will fit pressures as follows:

110	Pressures	from	99	to	122.
220	"	"	198	to	244.
440	"	"	396	to	488.
500	"	"	450	to	550.

It would, of course, have been more symmetrical if we had been able to give 550 as our highest low-pressure standard, but unfortunately up to the present our Board of Trade, which is the ultimate controlling authority, has not sanctioned a higher maximum than 500 volts, so we are obliged to depart from symmetry at this point. As a matter of fact these voltages appear to be very suitable and to fit very well with existing practice both in England, America and Germany, 110 volts being almost universal as the standard pressure for ship lighting.

Standard High Pressures.

The two sets of standard high pressures, namely those at the terminals of the generators and at the primary terminals of the transformers, were fixed by a committee presided over by Mr. C. L. Sparks. It was found convenient to settle on the even figures of 2000, 3000, 6000 and 10,000 volts at the primary terminals of the transformers, whereas those at the terminals of the generators were necessarily 10 per cent higher. The standard pressures at the secondary terminals of the transformers were fixed so as to

allow of a 5 per cent drop in the low pressure distribution system in order to fit into the standard pressures laid down as above at the consumers' terminals.

Frequencies.

We next had to deal with the vexed question of frequencies. Originally two frequencies, one of 50 cycles and another of 25 cycles were proposed. Some engineers went so far as to demand a third in the interests of turbine generators and rotary transformers. but after much correspondence, at a conference at which the views of all who held strong opinions on this matter were considered and voted on, a strong majority was of opinion that 50 cycles should be fixed as the chief standard frequency with 25 cycles as a subsidiary frequency for such power schemes or other uses where the lower frequency was specially desirable.

This work took many months but as at the same time Dr. Glazebrook was carrying on the work of his committee, which had been appointed to investigate the question of the safe limit of temperature at which electrical machinery can be worked for lengthened periods, no time was lost thereby.

Determination of Physical Constants.

The points to be investigated by Dr. Glazebrook's committee were the following:

1. The maximum temperature to which the insulating materials used in the manufacture of electrical apparatus can be exposed for lengthened periods of time without electrical or mechanical deterioration.

2. The relation between the mean temperature of any coil obtained by the measurement of rise of its electrical resistance and the maximum temperature at the hottest part of the same coil, obtained by inserting thermojunctions at these points.

3. The permissible rise in temperature and the best and most certain methods of measuring the same deduced from this experimental work.

A long series of experiments, lasting many months, was carried out by this committee, principally at the National Physical Laboratory, but other check determinations were carried out at the works of those of the electrical firms who wished to aid the labors of the committee. Moreover, in some cases, it was desirable to repeat the temperature measurements on coils made at the National Physical Laboratory on the same coils when eventually mounted

in position on the generators, motors or transformers for which they were intended. Some of the results thus obtained are embodied in excerpts from reports which I have attached as an appendix to this paper.

Points already Determined by Physical Constants Committee.

Although the labors of Dr. Glazebrook's committee are not yet complete, sufficient work has been done to show that although both in America, Germany and England up to the present a maximum temperature of 50 deg. C. should not be exceeded in the hottest part of the coils and in a few cases when the work is intermittent, of 75 deg. C.; yet that when more accurate methods of determining the temperatures of the hottest parts of the coils have been laid down considerably higher temperatures may be allowed by our English committee when it issues its final test conditions, for many of the materials which are today used by the manufacturers for the insulation of coils and other portions of electrical machinery were actually subjected for periods up to nine months to a steady temperature of 100 deg. C. without either electrical or mechanical deterioration. It has also been shown that the maximum temperature reached by the hottest part of the coils that are nowadays used can never reach a point more than 25 deg. in excess of the average temperature of the coil obtained by percentage rise in the electrical resistance of the copper of the coil itself. It appears, therefore, that these materials may be exposed for great lengths of time to a temperature which when measured by rise in electrical resistance may be as high as 75 deg. C., which corresponds to somewhat less than 100 deg. C. at the hottest part of the coil.

Definition of Continuous and Intermittent Working.

Our committee found that manufacturers and users both attach great importance to clear standard definitions of what is meant by continuous and intermittent running. As regards the former, as it was generally admitted that the coils and hottest parts of generators and motors of modern type up to 100 kilowatts usually attain their maximum temperature within the limits of a six-hour full-load run, it was decided that a six-hour run should stand for the definition of continuous working; but as regards intermittent running, more especially in regard to crane and lift motors which work for short periods and stand so that their coils may cool down during the much longer periods between each run, it was found

very difficult to settle on a simple and clearly understood definition of intermittency. Many firms and users considered that the only definition of intermittent running would be that the intermittency should be defined by the customer, who should lay down a load factor on which the machine could be worked; but after much discussion this idea was abandoned as impracticable and a simpler, although admittedly imperfect, definition of intermittency was settled by the test run being reduced from the six hours of continuous running to one hour's running at full load.

Pressure Rise in Alternators.

The difficult questions arising out of the pressure rise in alternators were very sharply debated by Mr. Sparks' subcommittee and the definitions were only arrived at after much correspondence and many meetings. In their present form, however, they appear worthy of consideration as a satisfactory solution of this important question.

Standard Test of Generators and Motors.

Finally I come to the most important advantage that standardizing offers to manufacturers and users — that is, the issue of standard lists of sizes. We first issued a list of standard motors. We cut down the number of sizes from $\frac{1}{4}$ horse up to 100 horse to 15 for direct current, to 11 for single-phase alternators and to 17 for two and three-phase alternating motors. We were also able to issue a list of direct-current generators from 6 to 100 kilowatts comprising only 10 sizes, and of these we found that in the case of the direct-current generators all but the largest size could utilize the frames of nine of the standard motor frames.

Speeds Fixed for Alternators.

For larger generators above 100 kilowatts, we found the matter to be more difficult. Most of these larger generators are direct-coupled to prime movers, and we have been compelled to await the labors of our subcommittee on prime movers before we can issue our final list for large sizes. Luckily, in this case, the fact that the speed in revolutions per minute for alternators is fixed for us by the standard frequency and by the number of poles has enabled us to issue a preliminary list of nine standard sizes and speeds for direct and alternating generators ranging from 100 up to 1000 kilowatts, which appears to be convenient, and for the reason above given the speeds of these cannot be varied.

Progress with Transformers.

Of the work which remains to be done, that on transformers is nearly complete but awaits the labors of Dr. Glazebrook's final recommendations on temperatures. That of standard test conditions is not so advanced but will be recommenced in October when we have Dr. Glazebrook's results before us. The permissible variations from standard require extreme care.

Effect of Large Margin of 10 *Per Cent Allowed on Pressures on Motor Design.*

I have mentioned the one case where, in order to fit existing electrical pressures, 10 per cent variation must be allowed to enable these pressures to be served by our standard sizes. Manufacturers have informed us that this can be done, but it is evidently desirable in the future that the number of large centers of distribution that use pressures away from the standard pressures now laid down must gradually be reduced so that the large 10 per cent limit may be no longer necessary. This 10 per cent limit imposes on manufacturers of standard motors and generators a corresponding margin in the size of their standard patterns, and this margin cannot be reduced until the call for the plant to suit pressures 10 per cent away from the standards is greatly diminished.

The other classes of permissible variations to be standardized are those due to the necessary errors of instruments and observers in carrying out the standard tests.

In addition to these it would be advisable to standardize permissible variations due to small errors in manufacture or variations in the quality of the material. It would be probably advisable to fix two limits of variation from standard, up to the first of which the goods would be accepted and beyond which and up to a second limit the manufacturer would be penalized. In addition to these, as in some cases to the permissible errors, must be added those due to instruments and observers' probable errors; it may be advisable for simplicity sake to lay down a maximum scale including all such errors and variations for each class of measurement and which must in no case be exceeded.

Finally, I wish to call attention to the constitution of this committee. Out of 19 members only 7 represent manufacturing interests, two-thirds of the committee being composed of consulting engineers or users.

APPENDIX A.

Pressures and Frequencies.

The following are the resolutions with reference to British standard pressures and frequencies:

(1.) Resolved that the Standard Low Pressures for direct and alternating-current work, measured at the terminals of the consumer, be:—

110, 220, 440, 500, volts.

Though not included in the above standard pressures, 380 volts shall be considered as the recognized pressure to be maintained between the principal conductors in a three-phase system with neutral wire, the pressure then being 220 volts between the three conductors and the neutral.

(2.) Resolved that the Standard High Pressures for alternating-current work, measured at the terminals of the generator, be:—

2200, 3300, 6600, 11,000, volts.

(3.) Resolved that the Standard Primary Pressures for alternating-current transformer work, measured at the primary terminals of the transformer, be:—

2000, 3000, 6600, 11,000, volts.

(4.) Resolved that the Standard Secondary Pressures for alternating-current transformer work, measured at the secondary terminals of the transformer, be:—

115, 230, 460, 525, volts at no load.

(5.) Resolved that the Standard Direct-Current Pressure for tramway work, measured at the terminals of the motor, be:—

500 volts.

(6.) RESOLVED that the Standard Frequency for alternating-current work be:—

50 periods per second.

But where the circumstances of the case demand a lower frequency, a standard of 25 periods per second shall be adopted.

N.B.— The above Standard Pressures are subject to a permissible variation of 10 per cent on either side.

RATING OF GENERATORS AND MOTORS.

(Except for traction motors.)

1. Two rating shall be recognized by the British Engineering Standards Committee —

(A) Continuous Working.

(B) Intermittent Working.

(A) The output of generators and motors for continuous working shall be defined as the output at which they can work continuously for *six hours* and conform to the prescribed tests.

(B) The output of motors for intermittent working shall be defined as the output at which they can work for one hour and conform to the prescribed tests.

N.B.— The duration of test for machines above 250 kilowatts is still under consideration.

2. Every generator and motor shall carry, in a conspicuous position, a name plate giving the output and other particulars enumerated below.

In the absence of any statement to the contrary, the output given shall always be understood to mean the output for continuous working under Rating (A).

Name plates for machines under Class (B) shall bear the word "Intermittent."

3. The output and full-load speed marked on the name plate shall be those taken when the machine is at its normal working temperature, as determined at the close of the test run referred to above.

4. All generators shall have their outputs stated in kilowatts (K.W.).

All motors shall have their outputs stated in b.h.p.

5. The following information shall be given on the name plates:—

Generators	Direct Current.	KW.	Volts.	Amps.	R p m
	Alternating Current	KW	Volts.	Amps	Power Factor.
		Full Load Excitation	Volts. Amps	Frequency.	R p m.
Motors	D C. (Continuous working)	B H P	Volts.	R.p m	
	D.C. (Intermittent working)	B H P (Intermittent)	Volts	R p m	
	A C. (Continuous working)	B.H P.	Volts Frequency.	R p m Power Factor.	
	A.C. (Intermittent working)	B H P. (Intermittent)	Volts Frequency.	R p m Power Factor.	

The above applies to combined machines, such as motor generators, boosters, rotary converters, which shall have name plates giving information applying both to input and output.

Direct-Current Generators.

6. The list numbers represent the kilowatts which the machine can work at when operated continuously as a generator.

List numbers and speeds of direct-current generators (up to 100 kilowatts):—

List No.	Standard Motor Carcase.	R.p.m.	List No.	Standard Motor Carcase.	R.p.m.
6	7½	1,075	32	40	750
8	10	1,000	40	50	675
12	15	900	60	75	625
16	20	850	80	100	575
24	30	800	100	—	500

British standard generators of 100 kilowatts and above, whether for direct or alternating-current work, shall conform to the fol-

lowing list of sizes and speeds recommended for generators to be directly coupled to steam or gas engines.

KW	Revolutions per minute		
	Slow	Medium	High
100	*	250	500
150	*	250	428
200	*	250	375
250	*	250	375
300	94	214	375
400	94	214	375
500	83	214	300
750	83	188	250
1,000	83	188	250

N.B.—The "slow" speeds in the above table are tentative.

ALTERNATING-CURRENT GENERATORS.

7. British standard alternators of any type, in addition to the requirements laid down in previous clauses, in so far as the latter apply, shall conform to the following regulations:—

(a.) They shall give an e.m.f. curve which, under all working conditions, shall be as nearly as possible a sine wave.

(b.) For exciting the field magnets the standard pressures shall be:—

65, 110 or 220 volts.

(c.) The term "alternator" shall not include an "exciter." The latter, when necessary, shall be separately specified and subject to the regulations for standard direct-current generators.

(d.) The regulation of an alternator shall be defined as the difference between the rated full-load pressure and the no-load pressure with the same speed and excitation. This difference expressed as a percentage of the rated full-load pressure shall be termed the percentage "pressure rise" of the alternator.

(e.) They shall not have a greater percentage pressure rise than six per cent (6%) on a non-inductive load and twenty per cent (20%) on an inductive load, the latter being here considered as one having a power factor of 0.8.

This pressure rise may be tested on a non-inductive or inductive load according to the requirements of the specification.

The figures in (b) and (d) shall not apply to compounded alternators.

MOTORS.

8. All motors for the purposes of tests shall be rated under the following classes:—

(1.) Open.
(2.) Protected.
(3.) Ventilated.
(4.) Totally enclosed.

(1.) and (4.) require no definition.

(2.) A *protected* motor is defined as a motor, in which the armature, field coils and other live parts are protected mechanically from accidental or careless contact, so as not to materially interfere with ventilation.

(3.) A *ventilated* motor is defined as a motor in which while ventilation is provided for, access to the armature, field coils and other live parts is only to be obtained by opening a door in, or removing a portion of, the enclosing case.

N.B.—An alternating-current motor, class (3), in which the slip rings are outside the protection, shall be considered as coming under class (2).

LIST OF MOTORS.

9. The list numbers represents the b.h.p. which the machine can work at when running continuously as a motor, at the standard pressure of 220 volts, up to and including two (2) b.h.p., and above that size, at the standard pressure of 440 volts.

10. The following are the list numbers of British standard sizes of motors:—

List numbers (direct-current).

¼, ½, 1, 2, 3, 5, 7½, 10, 15, 20, 30, 40, 50, 75, 100.

List numbers (single-phase) 50 cycles.
1, 2, 3, 5, 7½, 7½A, 10, 10A, 15, 20, 25.

List numbers (two-and three-phase) 50 cycles.
1, 2, 3, 5, 7½, 7½A, 10, 10A, 15, 20, 25, 30, 40, 50, 50A, 75, 100.

11. List numbers and speeds of motors (up to b.h.p.).

DIRECT-CURRENT MOTORS.

List No.	R p m at full load	List No.	R p m at full load.	List No.	R p m. at full load.
¼	1600	5	1000	30	750
½	1400	7½	1000	40	700
1	1400	10	900	50	650
2	1100	15	850	75	600
3	1100	20	800	100	550

ALTERNATING-CURRENT INDUCTION MOTORS.

Single-phase, 50 cycles.

List No.	R p m at no load.	List No.	R p m. at no load	List No.	R p m. at no load.
1	1500	7½	1500	15	1000
2	1500	7½A	1000	20	1000
3	1500	10	1500	25	750
5	1500	10A	1000	..	....

Two- and Three-phase, 50 cycles.

List No.	R p.m. at no load.	List No.	R p m. at no load.	List No.	R.p m. at no load.
1	1500	10	1500	40	750
2	1500	10A	1000	50	750
3	1500	15	1000	50A	600
5	1500	20	1000	75	600
7½	1500	25	750	100	500
7½A	1000	30	750	...	...

The figures referring to alternating-current motors give the no-load or synchronous speeds; allowance should, therefore, be made for a reduction in speed at full load of, from about seven-and-a-half per cent (7½%) in the smallest motors to two-and-a-half per cent (2½%) in the largest motors.

APPENDIX B.

SUB-COMMITTEE ON GENERATORS, MOTORS AND TRANSFORMERS.

Proposals and Questions.

1. Proposed standard direct-current voltages to be within 10 per cent on either side of the following:

110	....	....	....	....	....	....
220	....	....	....	....	....	....
440	....	....	....	....	....	....
550	....	....	....	....	....	....

2. Proposed frequencies for alternating plant:

25 periods per second for power	....	....
50 periods per second for lighting	....	....

3. Names of British standard sizes of motors and generators:

....

It is proposed to give each size a list number, which is the b.h.p. which each machine can give off when running continuously as a motor at the standard voltages and at the revolutions as given hereunder.

4. Proposed list of sizes up to 100 horse-power:

List No.	R.p.m.				
$\frac{1}{4}$	1400	....	....	....	....
$\frac{1}{2}$	1400	....	....	....	....
1	1400	....	....	....	....
2	1100	....	....	....	....
3	1100	....	....	....	....
5	1000	....	....	....	....
$7\frac{1}{2}$	1000	....	....	....	....
10	900	....	....	....	....
15	900	....	....	....	....
20	900	....	....	....	....
30	800	....	....	....	....
40	750	....	....	....	....
50	650	....	....	....	....
75	600	....	....	....	....
100	550	....	....	....	....

N.B.—It is believed that manufacturers will find it convenient to stock frames or carcases of these 15 sizes only, as in most cases

the sizes will be governed by their use as motors, or if used as dynamos they will in most cases be belt driven. It is believed that in nearly all cases sizes larger than these will be coupled direct to prime movers and their speed and size will be governed by the corresponding makers' sizes of steam engines, gas engines, etc., so that a proposed list of these larger sizes cannot be circulated until the sub-committee obtain the views of the engine builders

. . . .

5. Give your views on the suitability of the above list as a standard list and add or delete any sizes you consider necessary or unnecessary . . . .

6. Standard test conditions not yet determined upon, but for preparation of above list it may be assumed that the maximum output is fixed by sparkless continuous working; maximum temperature reached not to exceed 50 deg. C. above that of atmosphere of test room . . . .

TABLE EXPLANATORY OF PROPOSED BRITISH STANDARD LISTS.

B.S. list No.	Motor outputs. 110 volts. B h.p.	110 volts. R.p.m.	220 Volts. B.h.p.	220 Volts. R.p.m.	440 Volts. B.h.p.	440 Volts. B.p.m.	Dynamo speeds. Amps.	110 Volts R p m.	150 Volts.* R p.m.	220 Volts R.p.m.	500 Volts R.p m
¼	¼	1,400	—	—	—	—	—	—	—	—	—
	1/10	650	¼	1,400	—	—	—	—	—	—	—
½	½	1,400	—	—	—	—	—	—	—	—	—
	¼	700	½	1,400	—	—	—	—	—	—	—
	1/11	300	¼	700	—	—	—	—	—	—	—
1	1	1,400	—	—	—	—	—	1,600	—	—	—
	¾	1,100	—	—	—	—	7	1,300	1,600	—	—
	½	700	1	1,400	—	—	4	800	1,000	1,600	—
	3/16	350	½	700	—	—	2	—	—	800	—
2	2	1,100	—	—	—	—	16	1,200	—	—	—
	1½	850	—	—	—	—	12	1,000	1,200	—	—
	1	550	2	1,100	—	—	8	700	1,000	1,200	—
	⅝	400	1½	850	—	—	6	—	700	700	—
3	3	1,100	—	—	—	—	25	1,200	—	—	—
	2	900	—	—	—	—	18	1,000	1,200	—	—
	1½	600	3	1,100	—	—	12	700	1,000	1,200	—
	1	450	2	900	—	—	9	500	700	1,000	—
5	5	1,000	—	—	—	—	40	1,100	—	—	—
	3½	700	—	—	—	—	30	900	1,100	—	—
	2½	500	5	1,000	—	—	20	600	800	1,000	—
	1¾	350	3½	700	—	—	15	450	600	800	—

* For charging accumulators intended to discharge at 110 volts.

7½	7½	1,000	—	—	—	—	60	1,100	—	—	—
	5	800	—	—	—	—	45	900	1,100	—	—
	3¾	500	7½	1,000	—	—	30	600	900	1,100	—
	2½	400	5	800	—	—	20	400	600	900	—
	1½	250	3¾	500	7½	1,000	15	—	400	550	1,150
	1	200	2½	400	5	800	10	—	—	450	950
10	10	900	—	—	—	—	80	950	—	—	—
	7½	700	—	—	—	—	60	750	950	—	—
	5	450	10	900	—	—	40	500	750	950	—
	3½	350	7½	700	—	—	30	400	500	750	—
	2	200	5	450	10	900	20	—	400	500	1,050
	1½	150	3½	350	7½	700	15	—	—	400	850
15	15	900	—	—	—	—	120	950	—	—	—
	10	700	—	—	—	—	90	750	950	—	—
	7½	450	15	900	—	—	60	500	750	950	—
	4½	350	10	700	—	—	40	350	500	750	—
	3½	200	7½	450	15	900	30	—	350	500	1,000
	1¾	150	4½	350	10	700	20	—	—	350	800
20	20	900	—	—	—	—	150	950	—	—	—
	15	650	—	—	—	—	120	750	950	—	—
	10	450	20	900	—	—	75	500	750	950	—
	7½	300	15	650	—	—	50	350	500	750	—
	4½	200	10	450	20	900	40	—	350	500	1,000
	3	150	7½	300	15	650	25	—	—	350	750
25	25	850	—	—	—	—	200	900	—	—	—
	18	650	—	—	—	—	150	650	900	—	—
	12½	450	25	850	—	—	100	500	650	900	—
	9	325	18	650	—	—	75	350	500	650	—
	6	200	12	400	25	850	50	—	350	450	950
	4	150	9	325	18	650	40	—	—	350	750
30	—	—	30	800	—	—	120	—	—	850	—
	—	—	22½	650	—	—	90	—	—	650	—
	—	—	15	400	30	800	60	—	—	450	900
	—	—	11	325	22½	650	40	—	—	—	750
	—	—	7	200	15	450	30	—	—	—	550
40	—	—	40	750	—	—	150	—	—	800	—
	—	—	30	600	—	—	120	—	—	650	—
	—	—	20	375	40	750	75	—	—	400	850
	—	—	14	300	30	600	50	—	—	—	700
	—	—	9	200	20	400	40	—	—	—	500

TABLE EXPLANATORY OF PROPOSED BRITISH STANDARD LISTS.—(*Concluded*).

B S. list No.	Motor outputs.						Dynamo speeds.				
	110 Volts.		220 Volts		440 Volts.		Amps	110 Volts R p.m.	150 Volts R p m	220 Volts R p m	500 Volts R p.m.
	B.h.p.	R.p.m.	B.h p.	R p m.	B.h p.	R.p m.					
	—	—	50	650	—	—	200	—	—	700	—
	—	—	37½	—	—	—	150	—	—	550	—
50	—	—	25	325	50	650	100	—	—	350	750
	—	—	18	250	37½	500	75	—	—	—	600
	—	—	12	175	25	350	5	—	—	—	400
	—	—	75	600	—	—	300	—	—	650	—
	—	—	55	450	—	—	240	—	—	500	—
75	—	—	37½	300	75	600	150	—	—	325	700
	—	—	27	225	55	450	100	—	—	—	550
	—	—	18	150	37½	300	80	—	—	—	350
	—	—	100	550	—	—	400	—	—	600	—
	—	—	75	450	—	—	300	—	—	450	—
100	—	—	50	275	100	550	200	—	—	300	650
	—	—	36	225	75	450	150	—	—	—	500
	—	—	24	150	50	300	100	—	—	—	350

APPENDIX C.

SUB-COMMITTEE ON GENERATORS, MOTORS AND TRANSFORMERS. DIRECT-CURRENT MACHINERY.

PROPOSALS AND QUESTIONS.

British standard sizes of motors and generators for direct current.

1. It is proposed to give each size a list number which gives the b.h.p. a machine can work at when running continuously as a motor. The motors to work at the standard pressure of 220 volts up to and including* b.h.p., and at the standard pressure of 440 volts above that size, at the speeds as given below.

2. Proposed list of sizes of motors up to 100 b.h.p. List numbers ¼, ½, 1, 2, 3, 5, 7½, 10, 15, 20, 30, 40, 50, 75, 100.

N.B.—It is believed that both manufacturers and users will find these sizes sufficient, as in most cases the sizes will be governed by their use as motors. Motors required to run at speeds other than shown in the list can be met by variations in the winding.

This applies equally to their use as generators.

The standard conditions of the test which will accurately define the output of each size will be circulated later.

I. BHP.	II. Revs per min at full load.	III. Revs per min. at no load.	IV. Revs. per min. at full load.	V. Revs. per min. at full load.
¼	1600	1500	......	......
½	1600	1500	......	......
1	1600	1500	......	......
2	1600	1500	......	......
3	1500	1500	......	......
5	1350	1500	......	......
7½	1300	1500	......	......
10	1200	1500	......	......
15	1100	1000	......	......
20	1000	1000	......	......
30	850	750	......	......
40	750	750	......	......
50	750	750	......	......
75	650	600	......	......
100	600	600	......	......

* This figure is under consideration.

3. The speeds given in column II are those suggested by the sub-committee after correspondence with the large users and manufacturers of motors. If you do not approve of these speeds, kindly insert in column IV the speeds you consider most suitable to meet ordinary commercial demands.

4. If you deem it advisable to standardize a second list of notably lower speeds kindly insert the figures you suggest in column V.

For comparison, the speeds settled upon for the alternate-current motors for the sizes stated are given in column III.

5. Do you consider it advisable to standardize the diameter of the pulley end of the shaft?

6. In the event of a conference being arranged, please state whether you would be prepared to send a representative to lay your views personally before the committee.

APPENDIX D.

Tubular Tramway Poles.

1. The poles shall be of mild steel free of all defects and shall be of three classes.

Light Pole. Medium Pole. Heavy Pole.

2. The sectional poles shall be either solid drawn, or lap-welded wrought steel, free of all defects, made up in three sections, swaged together when hot so as to make a perfect joint. The lap-welded seams in the sections shall be set at an angle of one hundred and twenty degrees (120°) to each other.

The taper poles shall be of wrought steel, free of all defects, rolled in one length and butt welded the entire length. The butt welding shall be carried out at an even temperature without overheating and no pole shall show any signs of burning at the weld.

3. The overall length of any pole shall be thirty-one feet (31 ft).

4. The length of the telescope joint in the sectional poles shall be eighteen inches (18 ins.).

5. The length of the sections shall be:

Top section	8 feet 6 inches.
Middle section	8 feet 6 inches.
Bottom section	17 feet.

6. The outside diameters, in inches, of the three classes of both sectional and taper poles, shall be:

SECTIONAL POLES.

Class.	Top.	Middle.	Bottom.
Light	5½ ins.	6½ ins.	7½ ins.
Medium ...	6½ ins.	7½ ins.	8½ ins.
Heavy	7½ ins.	8½ ins.	9½ ins.

TAPER POLES.

Class.	Top.	Outside diameter 9 feet, 6 inches from base.
Light	4¾ ins.	7½ ins.
Medium ...	5¾ ins.	8½ ins.
Heavy	6¾ ins.	9½ ins.

7. The thickness of metal in any pole shall not be less than one-quarter of an inch (¼ in.).

8. The completed poles shall be straight and true over their entire length to within one-quarter of an inch (¼ in.).

9. The section of any pole shall be as nearly circular as possible, not varying in diameter by more than one-sixteenth of an inch (1/16 in.) from the adopted standard.

10. Five per cent of each class of sectional pole shall be subjected to the following drop test:

The pole shall be dropped vertically, butt downwards, three times in succession, from a height of 6 ft. on to a hard wood block 6 ins. thick laid on a concrete foundation, without showing any signs of telescoping or loosening of joints.

11. Five per cent of each class of both sectional and taper pole shall be subjected to the following bending tests:

The pole shall, in each case, be rigidly supported for 6 ft. from the butt, and loaded, as a cantilever, eighteen inches (18 ins.) from the top, the load being applied at right angles to the axis of the pole which shall be fixed horizontally. Upon the application of the following loads in lbs., the temporary deflection and permanent set, measured at the point of application of the load, shall not exceed the figures stated in the tables.

Class of pole.	Load in lbs for temporary deflection not exceeding 6 ins.	Load in lbs for permanent set not exceeding ½ in.
Light	750 lbs.	1,000 lbs.
Medium	1,250 lbs.	1,750 lbs.
Heavy	2,000 lbs.	2,500 lbs.

12. In the event of the poles not fulfilling the test requirements, a further 5 per cent shall be subjected to the tests enumerated above; should any pole fail, the whole parcel from which the poles have been selected shall be liable to rejection.

13. The maker, at his own expense, and to the satisfaction of the engineer, shall provide all the necessary testing apparatus at his own works.

Discussion.

Chairman Steinmetz: We have before us for discussion the paper of Col. Crompton, on Standardization. It is an extremely important subject. As many of you probably know, the American Institute of Electrical Engineers appointed a Committee on Standardization, I believe about seven

years ago. This committee devoted two years to a very careful study of the question of standardization, and then issued a report, which was accepted by the American Institute, published, and has become practically the universal standard of the American industry. The committee has remained in existence since that time, improvements have been made, and the report reissued; but the original work of the committee has remained practically unchanged. No defects have been found, and in a short time the work of the committee has proven to be extremely successful.

Our English brethren are now considering the same problem, are endeavoring to adopt standards, and they have had the kindness, through Col. Crompton, to bring the matter before us to endeavor to see if some way could not be found of getting, not merely an American standard or British standard, but to come to an agreement, at least in a number of important matters, which would extend beyond the national limits. Therefore, this matter ought to be given very careful consideration, since it is of the utmost importance. I therefore call for discussion on this paper.

Mr. John W. Lieb, Jr.: A paper of this kind requires much more mature consideration than any of us have been able to give to it; however in looking it over hastily there is one point on which I fear it will be rather difficult to arrive at an agreement, certainly not without a compromise, and that is the question of the standard frequency. In this country the standard frequencies have practically come down to sixty cycles per second for cases where the major portion of the energy is to be used directly for lighting purposes, and twenty-five cycles per second where the supply to motors is predominant and for the operation of converters.

We read in the recommendations made by our colleagues of the Institution of Electrical Engineers of Great Britain that they favor a frequency of fifty cycles and twenty-five cycles respectively. It will now be desirable to give a careful study of the question as to whether it is practicable to get together. I must say that in looking over this paper, it strikes me that it covers an enormous amount of work, and it is hardly possible, in the brief opportunity we have had to examine it, to take it up in detail.

Col. Crompton: Mr. Chairman, permit me to suggest that perhaps it might make it easier if there are important questions arising one after another, to take this frequency question, discuss it by itself, and go to another, and finish off each one at a time. Then I should be able to answer on each one in turn.

Chairman Steinmetz: Gentlemen, while we are all extremely interested in the question of standardization, there is one difficulty to be met, and that is this — in standardizing as in legislation, whatever we do is dependent upon the decision of the supreme court, which has to decide whether our action is constitutional, as things exist in the States, or not constitutional. If the supreme court decides adversely, legislation is in vain. Unfortunately, in the matter of standardization, we have not only one, but three supreme courts — there is the consulting engineer, there is the large operating company, and the large manufacturer. If they do not agree to accept the results, standardization is in vain. I have been connected with the American side of standardization since the beginning, and could tell quite a tale of woe, although we have been extremely care-

ful to avoid as much as possible anything which may not be approved. We have found that standardization of nomenclature, of methods, of testing, etc., are well received and have been universally adopted. We have been successful in getting universal recognition for all those standards of numerical values, as pressure, operating volts, temperatures, generators, motors, transmission, etc., where we have selected these values which had already been adopted by the best practice of the electrical engineering profession. We have not been as ambitious as our English friends are in attempting to standardize speeds and sizes, because we very soon realized that would be in vain, because the manufacturers would not adopt the size and the customers would call for different sizes, and the manufacturers would supply these different sizes. In some cases of standardization, in a few instances we have had this experience where we standardized certain frequencies and certain voltages, but the industry went away from those and selected something else, and we had to revise our standards.

As I look over the paper, the main and foremost stumbling block in the way of agreement between the two countries would be the frequency of fifty cycles. In the United States fifty cycles was tried to a limited extent in 1892 and in 1893, but very soon the electrical engineer drifted away from fifty cycles and universally adopted sixty cycles. All the other frequencies, forty cycles, 125 cycles, etc., have disappeared. There remain only twenty-five cycles and sixty cycles, but the amount of machinery existing here in sixty-cycle apparatus is so enormous, is so universal over all the country that I fear that any attempt to change the standard frequency would merely result in introducing, to a more or less limited extent, an additional frequency of fifty cycles, without eliminating the sixty-cycle apparatus, though I personally, and most of us here, would desire a standard frequency in unison with our English friends and would be willing to accept fifty cycles. I grant even that if you go before the large manufacturers, they would say, "Yes, we would prefer fifty cycles to get together with our English friends;" and they would be willing to accept fifty cycles; but when you look at the balance sheets of the next years you would find 90 per cent of the apparatus to be sixty cycles and 10 per cent to be fifty cycles, at the best.

We had similar experience with the transformer ratios in the first standardization report. The standard ratios of nine to one and eighteen to one were adopted, and all manufacturers accepted it, but when in the revision we investigated the statistical data, we found that although the manufacturers had adopted the nine to one ratio as standard, they built several times as many ten to one transformers, as nine to one transformers, and we concluded then that we would have to give the nine to one ratio up. Although everybody was willing, it was not possible to carry it through, and I am afraid the case would be the same with fifty cycles. Therefore we should like to hear from our English friends the reasons for their adopting fifty cycles. I know on the Continent it is used to a very large extent, and I know a compromise by sacrificing fifty cycles in favor of the American standard of sixty cycles would be expecting very much from our English friends; but at the same time, for the sake of harmony between all branches of the electrical industry, here and abroad, I hope it

can be arranged, because I can see that it would be practically impossible, nay, it would be indeed impossible to secure a change of frequency in the United States from sixty to fifty cycles, since sixty cycles has now been adopted as a universally recognized standard in this country for six years or more, and everything else has disappeared. Abroad it is not quite as bad as that yet In addition to fifty cycles, there are still sixty cycles, eighty-three cycles. forty-two cycles, forty cycles, and other frequencies, and so it may still be possible to direct the industry abroad towards sixty cycles

Col. R. E. B. CROMPTON: A heavy responsibility rests with me as I have to answer for my colleagues on the English Committee who have carried the work of electrical standardization up to its present point. I will do my best, but I speak with a full sense of responsibility.

I must first explain that in England we are somewhat favorably situated as regards enforcing standardization. I do not think that you have in America any body that commands so much authority in this respect as our English Institution of Civil Engineers. That Institution is the parent of all the English technical institutions, and is of such standing and position in regard to them that it is able to carry public opinion with it to a far greater extent than younger bodies such as our Institution of Electrical Engineers would be able to do, as nearly all the electrical engineers of position in the United Kingdom are also members of the Institution of Civil Engineers, so that not only we, the electrical engineers, but every member of the Institution of Civil Engineers are practically bound to support and carry out to the best of their ability any reasonable decisions which may be arrived at by the Engineering Standards Committee of Great Britain, which was appointed by the Institution of Civil Engineers and is administered through its officers.

In this way our British Standards Committees, whether they are standardizing steel sections, tramway rails, pipes or the electrical standards we are now considering, have enormous powers. They are able to carry with them our Home Government Departments, the Government Departments of our Colonies, so that we have reasonable hopes that all well-considered proposals for standarization will be successful in Great Britain to a far greater extent than has been possible in any other country.

In carrying on this discussion it will be convenient if I am allowed to take each question as it arises and discuss it by itself, commencing with the frequency question. As the question of the adoption of fifty-cycle frequency was very fully debated not only by the Committee but at a conference at which a large body of engineers and users, representing all the interests affected, were present, including among them many representatives of American manufacturing firms, I must first tell you that no one raised his voice in support of the sixty-cycle frequency you use to such a considerable extent in America. At our conference the chief reason why sixty frequency was not considered satisfactory was that it introduced difficulties in using converters when on circuits worked by internal combustion engines or any other engines in which the turning moment is not very uniform. On account of this difficulty, at one time there was quite a strong party in favor of introducing forty frequency, but against this strong evidence was produced that such a low

frequency could not be advantageously used for lighting purposes on account of ill effects on the eye-sight. As regards twenty-five, as a second frequency, it was evidently an enormous advantage that if two frequencies were adopted one should be exactly one-half of the other. Summarising, therefore, the chief arguments in favor of fifty frequency were.

1. Its very general adoption in England and on the Continent.

2. That it is altogether the best which allows of rotary converters without affecting the quality of the light, and,

3. That it allows of the half frequency of twenty-five, which is practically universally used as a lower frequency.

CHAIRMAN STEINMETZ: I call on Mr. Charles F. Scott, of Pittsburgh, to give us his opinion of the possibility of standardizing.

MR. SCOTT: As I listened to Col. Crompton yesterday, I thought that I probably knew what he was talking about a little better than many of the others present, as I had been in England some two years ago, and while there had given some consideration to the subject which is treated in his paper. In looking over the catalogues of manufacturers in England and on the Continent, I found that there was something which was amazing to an American engineer. The variety of ratings, of voltages, and of frequencies is something astounding. One manufacturer would have made probably three or four lists of induction motors for different frequencies. Some would give voltages which had never been heard of in America as standard voltages, and others would seemingly despair of a classification of voltage, and simply say motors up to five horse-power, any voltage up to 500; or, motors up to fifty horse-power, any voltage up to 3000. In America we are keeping closer to standards. We have not had the variety in the past, I think for several reasons. One is that America is one country, not divided politically or by different languages. We have been more of a unit. Speaking generally our engineers have not been of different nationalities, and of different surroundings, but in general they have been reared under the same common American influences, and most of them have come from the same American universities, assisted, it is true, by engineers who have been educated abroad, altogether making a common unit such as has not existed elsewhere. Another reason for American standards is that in America the lead in electrical work has been taken by a few large companies. Disregarding the merits, or demerits, from the commercial standpoint, of great corporations, a few large companies have certainly done good work in crystalizing and systematizing engineering work. Again, the American Institute of Electrical Engineers in taking up these problems definitely a number of years ago through its Standardization Committee has done most excellent work, and this is quite probably one of the reasons for the agreement between the present standards proposed in Great Britain and those in America, as our code of standardization has been before the engineers of Great Britain, to be followed if practicable.

In the paper under consideration a very wise caution is given that only those things should be standardized and the standardization done in such ways as will not limit progress. Now, while the British Board of Trade

may be an excellent thing as a supreme court and police department in enforcing standardization, some of us in America have gotten the idea that in a way it is restrictive; that you cannot go ahead as rapidly commercially; that rightly or wrongly it is restrictive, and if you get to certain standards, certain sizes, certain thicknesses, and go into matters of electrical design and detail, there is a danger that you will stop there — that the inventor and the designer may be restricted in their work. We may place a limit at certain temperatures that are common with certain materials, and that may be all right; but we may discover other materials in which a rise of temperature twice as great would be allowable; or for certain service we may find that alternators, which may be specified to have 6 per cent regulation, would be just as acceptable in service at 10 or 12 per cent. There is a danger, if we make our standards too rigid, that we cannot commercially take advantages of changes in materials and in design which would really give us more effective results.

In a measure, if this standardization is not made as a code of law to be enforced by a supreme court, but is given as a guide to desirable standards; if many of the things which are in commercial controversy are left to be worked out by the laws of competition, indicating the general lines along which we are to go, there are advantages which are well worthy of consideration.

You will find, as Dr. Steinmetz has pointed out, that many of the features in our American code have been accepted. The manufacturer, the selling agent, the operating company, cares not particularly about units, or names, or prescribed methods of test — they are incidental things. If a code is furnished which will serve as a guide, they are only too glad not to elaborate something new, but to accept what has been worked out for them.

I note one thing which makes this report all the more valuable, and that is that the manufacturers have been called in to assist in giving their opinions. Manufacturing companies, and the engineers and designers connected with the manufacturing companies, I think have had more sway in the development of American engineering than they have had abroad. The consulting engineer, for whom there is a most important field and place, I think is apt to get out of what we would consider his proper place in endeavoring to do too much designing, and it is largely for that reason that the standards abroad are so chaotic. As a foreign engineer expressed it to me, the engineer in his country — which happened to be France — was somewhat of an artist. He wanted to build up a new plant according to his own ideas — if he simply followed somebody else, there was nothing individual in his effort, any more than an artist would deserve merit if he simply copied some one's else pictures. He wanted to build up a new system, and if he could find a voltage or a frequency that was a little better adapted to his particular place, according to his opinion, why, that was undoubtedly the thing to use. There are quite different ideas from what we have here, and I think ours are well worthy of due consideration.

I question a little, on the other side, whether we need a supreme court to enforce such a code as proposed. These are engineering matters, and we ought to be able to lay down good engineering principles which people

will follow of their own accord; and not to make our engineering standards matters to be enforced and held to in all cases, but standards which will be generally recognized as suitable and acceptable. You lay down a certain diameter of pole for trolley road construction. Let the commercial public accept that as a standard of excellence; but if inventors or manufacturers can make something else, or do something better by varying one way or another from the recommended standard, very good; but there is an accepted, definite, standard of excellence. I may be swinging the pendulum a little too far in saying that this code should simply be merely a standard of excellence, but I want to emphasize the point that we must not make these standards too hard and fast.

In regard to the question of frequency, some two years ago I made a careful study of the subject of frequency abroad and frequency in America. I had every reason for desiring to find that sixty cycles would be a desirable frequency to use in England, because it conformed to the American standard. Taking a general observation of the frequencies used abroad, of the tendency in Europe toward fifty cycles, of the amount of work done at or near fifty cycles in England, and of certain advantages in the use of rotary converters and of slower speeds with fifty cycles, it seemed to me that it would be practically impossible, and from the standpoint abroad probably undesirable, to adopt a higher frequency. That is in certain ways not a matter upon which we need to agree as much as on many other things. The use of a common frequency would be felt particularly in the commercial exchange of apparatus; it is a commercial rather than an engineering question, and it would be highly desirable to have the common frequencies, but while desirable, I hardly regard it as fundamental.

I want to emphasize what has been said about the comprehensiveness with which this work has been done; it is a good example for us, and I hope permanent means may be taken by which the two countries, as well as other countries, may have their common standards of excellence.

Dr. R. T. Glazebrook: As a member of the English committee here, may I add a few words to what has been said, although I claim no particular technical knowledge on any of the points that have been raised. I think our warm thanks are due to Mr. Scott for what he has said and for the cordial reception generally which has been given to this idea of standardization; but the point I particularly wish to enforce is that there is no attempt in England to establish a definite hard and fast rule, or establish any supreme court or court of appeal which shall lay down the law and say that electrical machines must be of this or that form.

The idea, I am confident, that has animated practically all the members of the committee who have worked at this subject is that which Mr. Scott put forward just now — to indicate to the best of our ability what seems to be the best form of the machine in certain essential particulars, and to leave it to the common sense of Englishmen — which is not, I venture to think, inconsiderable,— to adopt those forms if they see fit, feeling sure that, if the committee had made a good selection, these forms will be generally used and adopted. I think I may say that there will be no intention whatever on the part of the English Board of Trade, or any authority of the kind in England, to insist on standards such as

these, without the possibility of change. I am not quite certain as to whether Mr. Scott is not a little confused, perhaps, between the action of the Board of Trade now and some unfortunate legislation that took place in England some few years ago. I am certain that the present officials of the Board of Trade are most anxious, in every way they can, to encourage the development of the electrical industry, and to encourage it on wise and good lines. They recognize the value of freedom, and I feel sure that they would deprecate any suggestion that they should act as a court of appeal to settle details as to standards of this kind. On certain points, legislation may have to take place, and then they will have to be consulted. Take, for example, one matter Mr. Scott referred to, the possibility of a variation in the temperature limits allowed in accordance with material used in construction That matter has been before our eyes throughout, and in the experiments which it has been my privilege to make, to determine, to some extent, what the limits of temperature should be, it has been clearly shown that materials used in the ordinary construction of machines differ considerably, and very possibly we may have to assign different limits of permissible temperature according to the metals used in the construction.

My sole object in rising, sir, was to thank the meeting for the way in which this paper has been received, and to assure you that we Englishmen value our freedom in this respect and intend in the future to act on it as in the past.

Prof. F. B. Crocker: The subject before the meeting is one to which I have given attention for a good many years. I had the honor of introducing in a Council meeting of the American Institute of Electrical Engineers in 1898 a resolution authorizing the appointment of a committee to take up the standardization of electrical machinery. Previous to that time, as a manufacturer and as an engineer,— I was fortunate perhaps in occupying both positions,— I had seen the necessity of some such action. That committee was appointed and I had the honor to be chairman of it. At first it was rather uphill work — many thought it was an attempt to force something upon them; so that some manufacturers resented the attempt, and there was a little trouble, but it all disappeared and now there is no trouble whatever. Another difficulty was anticipated — the fear that the Institute, having no authority to enforce the recommendations of the committee, would discover that the recommendations were ignored and no attention paid to them. That fear proved to be wholly unfounded, and I think we have succeeded, as the course of events has shown, in securing the adoption of these standards to a very large extent. The recommendations were reasonable; they were not enforced, but were acceded to and accepted very graciously, and everything has proven satisfactory.

I refer to this matter, because that question has arisen in regard to enforcing standards by the Board of Trade, a body which has the power to enforce such recommendations in England, which is not possible in this country. I think it would be wise for the Board of Trade or the authorities in England not to try to force matters. I think, as Mr. Scott says, it is wise to let people accept the recommendations and it is wonderful how

quickly and gracefully they do so, and how well satisfied every one is. All of which is very encouraging to those introducing standards.

Now as to the exact recommendations. I listened to Col. Crompton's paper yesterday with interest and carefully studied it outside of the meeting, and I think his recommendations are admirable in general. I think the 10 per cent allowance in voltage is rather large, but I understand, and in fact it is stated, that the allowance is made to bring the 550 volts in line with 500 volts. I think the 500 volts standard is undesirable.

Col. CROMPTON: That is something that is going to be dropped, the 500 volts. Since this paper was written I may tell you that the Board of Trade has practically consented to allow us to do something else.

Prof. CROCKER: I bring that up, however, as a point where the Board of Trade with its absolute authority can do harm, assuming that they do not drop the 500-volt standard. We have no such authority in this country. Our National Board of Fire Underwriters has authority which is powerful indirectly; but we have no board in our government that has authority in the same sense that the Board of Trade in England has power.

Then in regard to the ratings in transformer ratios, it is a mere detail, but is rather an odd ratio as it works out.

There is another point, nothing but a verbal one, but I protest against this use of the expression "slow speed." I do not know where it came from. Why not say high speed and low speed? I think in the catalogue of most of our manufacturers — I am afraid it is so in our own catalogue — the term "slow speed" is used. I do not see any reason for it. Low speed is better English and does not involve that curious contradiction in terms.

Another thing that Mr. Scott touched on which is important, and that is the tendency to lay down rules as to construction. I think that would be a mistake. You should lay down rules for *performance* only. I do not care if a man makes a machine with *no* poles, provided it operates at required voltage and amperes, with good regulation. In that case you have simply got rid of your poles. I do not see any sense in saying that poles should be sixteen and three-fourths inches wide. That is nonsense. The recommendations should be absolutely confined to performance and not attempt to cover construction. Be careful in your requirements of performance, but not as to the construction of a machine. These are the only points that occur to me.

CHAIRMAN STEINMETZ: I believe I voice your sentiments, gentlemen, in saying that we should be very pleased to hear from Mr. R. Kaye Gray, President of the Institution of Electrical Engineers of Great Britain.

Mr. GRAY: In regard to the question of standardization, I may talk of a general sentiment which exists in the Institution of Electrical Engineers, and also on the part of the members of the Standards Committee, I know; but to deal first of all with the Standards Committee, I had the pleasure of presiding over one of the sub-sections which dealt with cables and things of that sort. The remarks which I made to my subsection were absolutely those made by Mr. Scott. I said I believed the

instructions from the general body were that we were to lay down, if you will call it such, a model specification, in the hope that it would by its reasonableness be adopted by the profession. I do not believe there was any intention even, to make these things in the form of castiron rules; but it was our idea that when a number of men of such ability got together and drew up certain specifications, these specifications would appeal to all other reasonable men and they would doubtless follow along the same general lines. I may mention that all the manufacturers were consulted in these matters, and what we have drawn up in connection with the cables has certainly been the result of deliberation between all classes of the community on our side. With regard to the other question, so far as the Institution of Electrical Engineers is concerned, we went further and tried to make a certain amount of order out of chaos — we drew up certain model conditions, model conditions of contract, even, and I think now that some of these model conditions are being incorporated into many of the contracts on the other side;— not by any compulsion, but simply because they were so reasonable that consulting engineers and others thought it advantageous to fall into line and to adopt them.

I do not wish to discuss the technical matters treated of in this paper, but think, now that you have called upon me to speak, it is my duty to say in the words I have used that there is no intention whatever on the other side of the Atlantic to put obstructions in the way of progress.

CHAIRMAN STEINMETZ: We should be delighted to hear from Prof. M. Ascoli, President of the Associazione Elettrotecnica Italiana, and secure some information on the subject of standardization as it exists in Italy.

Prof. ASCOLI: I have followed this interesting discussion, but I cannot express myself as clearly on the subject as the speakers who have preceded me. The question of standardization has not yet come up for discussion before our association in Italy, and I can only say that I hope to bring it before the association.

CHAIRMAN STEINMETZ: Gentlemen, if there are no further remarks, I call upon Colonel Crompton to close the discussion.

Col. CROMPTON: I think there is little for me to say in reply. I am sure that President Gray and my English colleagues will agree with me that it will be a great pleasure to us to be able to report to our Standards Committees on our return to England that on the whole the general sense of the American engineers present at this conference agrees very closely with our own conclusions. I have gathered that excepting this one matter of the very considerable extent to which sixty frequency has been used in America, and which I admit makes the matter rather difficult, the chances of agreement between the two countries on this question of standardization of machinery are very good indeed. I am sure on one point we are absolutely at one. If you will read through the paragraph in my paper, middle of page 769, in which I point out the extent to which electrical standardization can be usefully carried, you will find how strongly we, the English Committee, feel that we must avoid standardizing design in any way. I agree thoroughly with Professor Crocker on this point, and I am sure I carry the opinion of my own Committee with me. We wish to standardize nomenclature, frequency, voltage,

test conditions and similar matters, and if possible to standardize ratings so as to minimize as far as possible the number of types which the responsible consumer or the consulting engineer can order. By such a standard list of ratings we can eliminate the special types, which the common sense of manufacturers and users has decided are not necessary as standard types. We do this in the interests of manufacturers as well as users. We do not wish manufacturers to be burdened by an increased number of patterns which we believe are practically unnecessary, and it is evident that by so limiting the number of patterns we facilitate the rapidity and economy of manufacture.

There is another point on which I should like to correct one or two of the American speakers including Mr. Scott, who have said that our English Board of Trade has been obstructive to us during recent years. The primary duty of our Board of Trade is to protect the public from danger in using electrical appliances, and from this point of view in the early stages of electrical development it did lay down laws as to thickness of insulation and the methods of carrying overhead wires which were to some extent restrictive, but it has now withdrawn those rules and has confined itself to issuing certain definitions of permissible voltages which must not be exceeded where the public have access to unprotected electrical terminals. Up to quite recently 500 volts was the maximum pressure practically allowed by our Board of Trade, but I am told that they are now considering allowing a somewhat higher voltage. I believe that our Board of Trade is now in harmony with our profession and is helping us. We know that we have the sympathy of its officials in the decisions our Standards Committee has arrived at. I think that in England we may be congratulated on this fact, that we have received the countenance of our government so that our standards organization is likely to be to some extent continuous and that our committees will be continued in future to consider from time to time any recommendations for improvements in regulations which now exist but which may eventually be found not to be in harmony with future discoveries. It appears desirable that standardizing, based on the opinion of the majority of engineers at any one time, is liable to be and should be corrected from time to time as our knowledge increases. With such an understanding standardization may go on simultaneously in all countries and I hope that those countries who wish to take the matter up will look on it in this light.

I thank you for the very kind attention you have given me in presenting to you this somewhat difficult subject, which after all is of supreme importance to most of us.

Mr. Lieb: I understand that this subject of International Standardization is a matter which is about to be, or has already been, taken up by the Official Chamber of Delegates of the Congress, and I wish therefore to propose a resolution to be passed jointly by sections B and E.

Resolved, that the matter of International Standardization be urged upon the Chamber of Delegates for their attention, and that also the American Institute of Electrical Engineers be asked to take up this question, and to place itself in communication with the Institution of

Electrical Engineers of Great Britain, for such further consideration of this subject as may seem advisable.

CHAIRMAN STEINMETZ: Gentlemen, you have heard the resolution, made as a motion, by the chairman of Section E, Mr. Lieb, and as chairman of Section B I take great pleasure in seconding the motion, and calling for discussion thereon. If there is no discussion asked for, which I believe is very proper, since I feel quite sure that we are in full harmony with this motion and resolution, I shall call for the question. All who are in favor of the motion will please say aye.

(The resolution was unanimously carried.)

I take pleasure in closing the joint session of Sections B and E, and turn the chair over to Mr. Lieb.

CONTINUATION OF SESSION OF SECTION E.

CHAIRMAN LIEB: We will now continue the sessions of Section E; and as we have still four papers and would like to dispose of three of them before we adjourn this session to-day, as our session to-morrow will be very crowded, I will ask that as far as possible a resumé of the papers be made, but it that is not practicable we will read the papers in full.

I will ask Prof. Ascoli to take the chair while a paper representing his society is read.

(Professor Ascoli in the chair.)

CHAIRMAN ASCOLI: We will now have the paper on "Stroboscopic Observations of the Arc," by Prof. L. Lombardi and Sig. G. Melazzo.

Prof. LOMBARDI. Mr. Chairman and Gentlemen, I feel a hesitation about presenting my paper; first, because of the extraordinary value of the two papers which were read this morning in Section E, to which my paper cannot add anything important on the subject of the arc between carbon electrodes; and second, because I am a very imperfect speaker of your beautiful language, which, perhaps, will not make it possible for me to be thoroughly understood. In this case I should like to ask our chairman to help me.

Professor Lombardi read his paper.

SOME STROBOSCOPIC OBSERVATIONS ON THE ALTERNATING-CURRENT ARC.

BY PROF. L. LOMBARDI, *Delegate of the Associazione Elletrotecnica Italiana,* AND G. MELAZZO, *Electrotechnical Institute, Naples.*

The peculiar phenomena which characterize the production and maintenance of an alternating-current arc between carbon or metallic electrodes are well known from the interesting work of Blondel, Fleming, Duddell and Marchant, B. Burnie, Rössler and Wedding, Görges, Neubach, Gold, Guye and Monasch, and many other experimenters.

As the current and pressure, and consequently the electric energy in the arc, vary within the limits of a single period, so too the heat and light emitted from the arc undergo definite variations. These variations, which generally result in an appreciable decrease of the luminosity of the arc, could be directly perceived if the time of a period were long enough; for lecturing and experimental purposes they cannot, however, be demonstrated without special methods.

The earliest method of studying short periodic phenomena of this nature was that of the rotating mirror. This gives during a period a continually displacing image which can be directly observed, or, by the interposition of a stroboscopic diaphragm, resolved into a number of instantaneous images at any given phase of the period, such as to be easily combined by the eye, or recorded on photographic paper.

Jamin and Roger as early as 1868 (*Comptes Rendus,* 66), observed by means of a rotating mirror the luminous oscillations of an alternating-current arc, and in 1895 S. P. Thompson (*London Electrical Review*) succeeded with the same apparatus in demonstrating the electromagnetic deflection of the alternating-current arc in the earth's field. In the same way some interesting results were obtained by Guye and Monasch (*Éclairage Électrique,* 1903), working on the alternating-current arc between metallic electrodes.

In his first research on the optical properties of the alternating

current arc, Blondel adopted the artifice of directly photographing a luminous band of the arc on a sensitive paper revolving at the same synchronous speed of the generator (*Lumière Électrique*, 42, 1891); a method which Street had already employed in 1882 for studying the light variations of a Jablochkoff candle. The method has the advantage of giving a continuous image of one part of the arc, which, in the study of some phenomena, is of very great use. It cannot, however, be utilized for purposes of demonstration, nor does it give, without modification, a complete representation of the phenomenon at any phase of the period.

Joubert in 1881 (*Journal de Physique*) suggested the first stroboscopic method, enabling the optical phenomena of the alternating arc to be followed by direct vision. The method was to observe the luminous source through a small opening in a stroboscopic disc, mounted on the shaft of the alternator feeding the lamp, or on that of a synchronous motor; observations being taken from different points so as to see the images corresponding to the different phases of the period.

The necessity of changing the position of the eye, however, makes the method unsuitable for purposes of demonstration. Joubert did not himself publish any results obtained by this method.

A fixed image of the arc, which can be observed directly or photographed, may be obtained at different phases by varying the position of the stroboscopic disc relatively to the shaft of the alternator or motor, or the position of the stationary portion of the machine, or, again, by modifying the phase of the current which feeds the arc lamp. These methods were adopted by Görges (*Elektrotechnische Zeitschrift*, 1895), Fleming (*The Electrician*, 1895), and B. Burnie (*The Electrician*, 1897), in some very interesting experiments, undertaken with the object of obtaining exact measurements of the thermal and luminous radiations of the alternating-current lamp with carbon electrodes at different phases.

In the same way Gold (*Sitzungsberichte* der Wiener Akademie, 1895) observed the alternating-current arc between two dissimilar electrodes — one carbon and one metallic — and detected a drop of liquified metal swinging on the tip of the metallic electrode and changing its form and dimensions with the direction and strength of the current. These observations led him to one of the most probable explanations of the remarkable variation in the resistance of the arc with change in the direction of the current.

In such methods, where a stroboscopic disc rotating at synchro-

nous speed is used, only a single image of the arc can be obtained resulting from the succession of many instantaneous images, which all correspond to a particular phase of the period. They are not, therefore, suitable for watching or demonstrating the momentaneous phenomena of the arc, which are never of a very stable character. It is easy though to introduce in the method a slight modification, so as to make it well adapted for both purposes.

If the disc be turned at a speed not synchronous with the alternations of the current in the lamp, but slightly below the synchronous speed, the successive images so obtained will not represent the arc always at the same phase in each period, but in phases each a small fraction of a period later than the preceding one. The less the speed of the disc differs from the synchronous speed, the longer will be the time required for a complete series of distinct images, following each other so rapidly as to give an apparently continuous reproduction of the periodic phenomenon on a very enlarged time scale.

The length of the apparent period of the phenomenon under observation may, of course, be regulated as closely as desired, by mounting the stroboscopic disc on the shaft of a small continuous-current motor, provided with a suitable regulating resistance. Or it may be rotated by an asynchronous motor, the size of which is very suitable to give a quite long apparent period, varying its length by changing the load on the motor.

Hospitalier was the first to describe an arrangement of this type, suitable for studying the luminous variations of an alternating-current arc (*The Electrician,* December, 1903), which he called an arcoscope. A short time afterward we came independently to use the same arrangement for our lecturing and demonstrating purposes. We started from the same principle on which Dr. Bellini (*L'Elettricista,* 1904) in the course of this year established his method of measuring the slip of an asynchronous motor, by counting the swings of the carbon filament of an incandescent lamp fed by the same alternating-current main and placed in a constant magnetic field. Dr. Benischke (*Elektrot. Zeitschr.,* 1904) has lately described a convenient apparatus, giving analogous results by counting the apparent revolutions of a disc, painted with differently colored segments, the disc being mounted on the shaft of the asynchronous motor.

In many of our experiments the stroboscopic disc was mounted on the shaft of a four-pole alternator, driven by belt from a shunt-

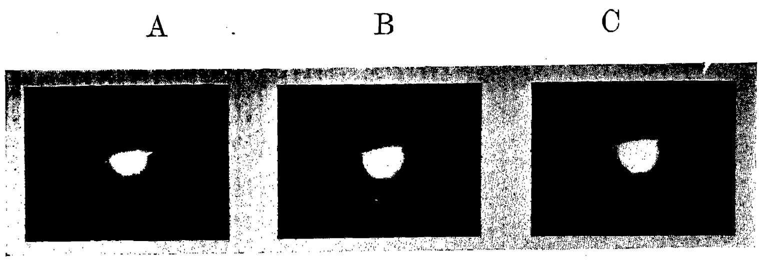


FIG. 1.

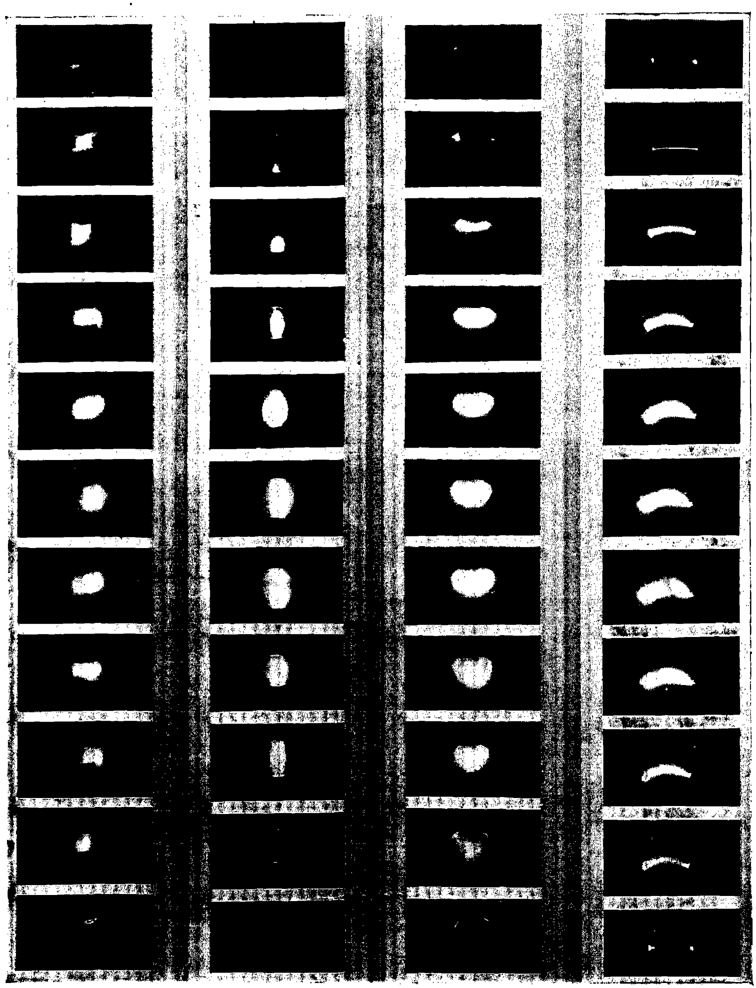


FIG. 2.

wound motor, fed with continuous current from the street mains or from storage batteries. The alternator itself could be run as a synchronous motor from the same circuit as the lamp, and in this way it was possible to get either an asynchronous speed, giving a continuous view of the periodically changing arc, or a synchronous speed, giving a permanent image of the arc at any definite phase of the period. The phase could, of course, be changed by turning the disc relatively to the shaft of the alternator. The various phenomena which accompany the production and maintenance of the alternating-current arc between carbon and metallic electrodes can be easily demonstrated in this way to a very large audience, and any particular feature of them can be closely studied and, if desired, reproduced photographically, by keeping one phase constantly in the field of vision. To give an idea of the suitability of a method of which we were not able to find any experimental result in electrotechnical literature, though we can claim nothing very novel in it, we show in the accompanying illustrations some sets of photographic views, reproducing the luminous images of different direct and alternating-current arcs between carbon and metallic electrodes, the last having been taken at equal time intervals throughout one period.

To get as standard of comparison a very regular image of a direct-current arc, we used a 10-amp. differential lamp of Siemens & Halske, fitted with a cored positive carbon and a solid negative one (Fig. 1). *A, B, C,* give views of the arc fed with different pressures respectively, of 44, 50, and 55 volts. As is well known, the electric arc arises in form of an exceedingly bright flame from the incandescent point of the negative electrode, increasing in width until it reaches the positive crater, at the surface of which the great electric resistance wastes the most of the power, and supplies the largest quantity of heat and light.

Coming to the Fig. 2, the first column shows ten different views of an alternating-current arc between the solid carbons of a shunt-wound self-regulating lamp; the second column the arc of the same lamp filled with cored carbons; and the third column the arc of a Ganz lamp, of the well-known differential type with impregnated, downwardly inclined carbons of yellow mark.

It would be out of place to repeat here the many interesting deductions made by Blondel from his photographic reproductions in 1891. Photography cannot reproduce the phenomena faithfully from an optical point of view, since the actinic power of the arc

is so high in comparison with its candle-power that there is no proportionality between the photogenic and the luminous effects. To make comparison easier, the time of exposure was in all cases the same, and was a very short one — some thousandths of a second. The stroboscopic disc made 20 revolutions per second, and contained two circular holes, 4 cms in diameter, on a circle of about 60 cms diameter. Although of small actinic power, the rays of greater wave length, coming chiefly from the flame (aureole) which surrounded the arc, were filtered out by interposing a violet-colored glass screen. The time of development and the strength of the fixing bath was, however, chosen so as to make the image in each case sufficiently clear.

When the current is diminished to a very low value, the arc breaks, and will not relight until the difference of potential between the electrodes exceeds a definite limit, depending on the form and nature of the carbons and the conditions of the electrical circuit. It is very interesting to follow the growth and extinction of the arc with different carbons. With cored and impregnated carbons it is formed by a small flame, rising more or less rapidly from the negative crater to meet the positive one, while with solid carbons the arc appears almost at once in its full length between the electrodes, growing in the form of a spherical globe which turns rapidly toward the edge of the carbons, and disappears quickly at the end of each half period. The growth of the arc is generally not so rapid as its decrease, as Blondel has clearly shown. The small actinic power of the incandescent carbons does not allow of a close comparison between the brightness of the positive and the negative craters.

As the ratios of the instantaneous values of potential difference and current intensity show (see Fig. 3), the arc between solid carbons undergoes greater resistance variations than that between cored or impregnated carbons. As a matter of fact, the potential rises at the beginning of the period to much higher values, and the power factor becomes correspondingly less. We found as average value of the power factor of the lamp for solid carbons to be 0.63; for cored carbons, 0.94, and for impregnated carbons, 0.86. The diameters of the carbons were respectively 12, 13, and 8 mm; the current strength was in each case about 11 amperes, and the potential difference 44, 37, and 39 volts, respectively.

In the case of metal electrodes, Aron has shown (*Wied. Ann.*, 1896) that their very high thermal conductivity, and the rapid

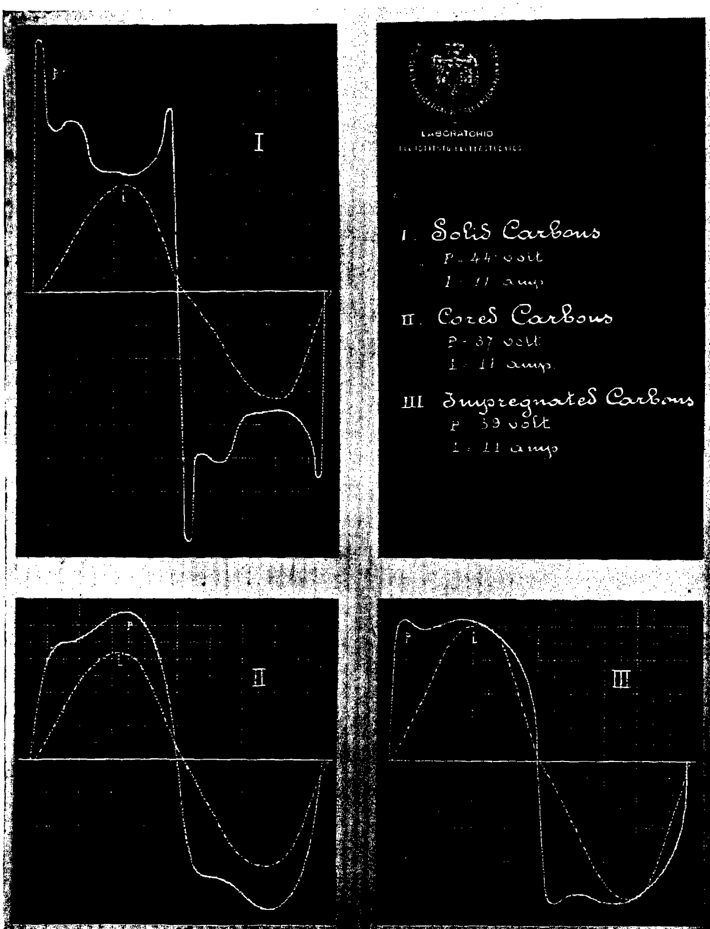

I
LABORATORIO
I. Solid Carbons
P = 44 volt
I = 11 amp
II. Cored Carbons
P = 37 volt
I = 11 amp.
III Impregnated Carbons
P = 39 volt
I = 11 amp
II
III

FIG. 3.

cooling of their vapor, prevents the arc forming again after an extinction, until the potential difference exceeds a definite limit, sufficient to cause between the electrodes a new disruptive discharge. The peculiar appearance of the arc, the electric elements of which were recently studied by Guye and Monasch (*Éclairage Électrique,* 1903), is clearly shown in the last column of Fig. 2, which gives a set of photographic views of the arc between two copper electrodes 5 mm in diameter, separated by a distance of 6 mm.

One can see at the beginning of the period the striking of a very brilliant spark from the negative electrode, which requires a very high momentary value of the potential difference, depending on the frequency of the alternations, the strength of the current, and the electric conditions of the external circuit. At the distance established by us between the electrodes, not less than 6500 volts were necessary to get the first disruptive discharge, the current being supplied by a large Ruhmkorff coil, the primary of which, by interposition of suitable resistances, was fed with alternating current of 40 cycles, 150 volts. The effective current strength of the arc was 0.06 ampere; the potential difference sufficient to maintain the arc was about 1200 volts.

As a matter of fact, although Lecher (*Sitzungsberichte* der Wiener Akademie, 1887) did not discover any difference between the resistances at the surfaces of the positive and negative electrodes, and Child (*Physical Review,* 1900–1901) was only able to detect a very small one, our photographs show a very appreciable distinction between the luminosity of the electrodes, which recall the particular aspect of the anode and the cathode of an ordinary induction apparatus.

Nevertheless, we can observe after the phenomenon has begun, the general characteristics of an ordinary arc, disappearing quite suddenly at the end of the period. We were not able, with the Joubert's apparatus which we had at our disposal, to get a correct reproduction of the curve of the periodical variation of potential and current under the same conditions as those of our photographic experiments, on account of the very small current strength and the high potential difference. It is, however, easy to understand that the electric resistance of the arc, owing to the rapid cooling of the metallic vapors and to the high thermal conductivity of the electrodes, must undergo enormous variations, and the pressure supplied by the induction coil must rise to exceptional figures in every alternation; the power factor in consequence becomes very

small. As average value of this power factor, Guye and Monasch give for similar copper electrodes 0.58.

By the same method we were able to follow, by means of appropriate voltmeters and selenium cells, the remarkable variations of the heat and light emitted in every direction from the carbon of the usual alternating-current lamps. Mr. Burnie has already given the general form of these curves, on which he made (*Electrician,* 1897) a very accurate study, measuring by means of bolometer and photometer the thermal and luminous radiations of the alternating-current arc between solid and cored carbons. The stroboscopic method which we made use of, availing ourselves of an asynchronous motor, makes it possible to demonstrate this variation without any difficulty in a very suggestive manner. On account of the large thermal capacity of the electrodes, the heat emitted from them varies very little, as Mr. Burnie has very well demonstrated, principally in the direction of the utmost heat intensity, where the measurements acquire the greatest accuracy. It is not possible, therefore, notwithstanding the apparent length of the period, to get exact results from the bolometer without using very delicate instruments. The optical variations, however, which are perhaps more important for the economy in the distribution of light, can be perceived directly, or can become, by use of selenium cells, the object of very accurate measurements.

It would have been very interesting to observe in the same way the luminous phenomena occurring in the new mercury vapor lamp and converter, which Mr. Cooper-Hewitt is now perfecting for use with alternating current. As is well known, such apparatus consist of a glass tube, exhausted to a high degree on a vacuum pump and filled with metallic electrodes; one of these, which always works as a negative pole, is mercury, and the others are iron or platinum wires. The mercury electrode is connected with the neutral point of a polyphase system, or if on an ordinary monophase system, with a neutral point obtained by means of a small auxiliary transformer. The other electrodes are connected with the mains of the alternating current, and become respectively positive during successive parts of a period. From the positive to the neutral, acting as a negative electrode, flows a current of definite strength, depending on the instantaneous value of the resistance and the potential difference. As the voltage begins to drop off, this current tends to drop too, and if there were no other electrodes it would soon become zero, the resistance rapidly increasing to infinity; but,

on account of the phase relation, another electrode becomes positive before the preceding current falls below a certain limit, thus keeping the current always in the same direction, and maintaining the arc. Such results are realized without difficulty on every system of three or more phases. In the case of ordinary monophase distributions, it becomes necessary to split the simple current into two with a phase difference of 180 deg.; for this purpose an inductive coil may be usefully employed to get the necessary difference of phase between potential and current.

Unfortunately the mercury apparatus of Cooper-Hewitt for alternating current is not yet on the market, and we were not able to procure one for studying the phenomena, as was our hope when we first announced this paper for the Congress. Nevertheless, we intend to proceed later in this direction, so far as the possibility to get suitable apparatus will permit of our doing so.

I will not, however, fail to mention here the interesting contribution of Mr. G. W. Pierce, who has carried out an important research on the Cooper-Hewitt mercury interrupter, in the Jefferson Laboratory of Harvard University, and by means of a rotating mirror obtained beautiful photographs of the luminous phenomena which take place. (*Proceedings* of the American Academy of Arts and Sciences, 1904.)

It is perhaps needless to point out that the method of taking stroboscopic observation by differential speed is applicable to many other phenomena of interest to the electrical engineer. The pendular swing of alternators run in parallel can, for instance, be easily observed by viewing the revolving part of an alternator through a stroboscopic disc which is rotated by a small motor run up to the speed of synchronism. The method is very simple and, we believe, more exact than the stroboscopic one used by Professor Görges (Elek. Zeit., 1900) in observing the angular oscillations of a colored mark, illuminated by an independent source of light of the same frequency.

Discussion.

Prof. C. P. Steinmetz: Mr. Chairman and Gentlemen, I want to take a moment to express my thanks to Professor Lombardi for his very interesting paper — the more interesting to me as it really proves photographically a number of points which I deduced in my paper; the character of the metal arc, which, being rectifying, is preceded by a disruptive discharge between the terminals, thereby resulting in a very high voltage, but unsteady character. I ask Professor Lombardi whether he noted in the

middle arc, in Fig. 4, any rectifying tendency. The two sides of the arc are dissymmetrical.

Prof. LOMBARDI: I did not take observations of the rectifying action of the arc, but I believe the arc will not in such conditions be a good rectifier, on account of the two electrodes being symmetrical. Perhaps we get just as much positive as negative current, because of the two electrodes being perfectly similar to each other. I have not had the opportunity of experimenting with such dissimilar electrodes as are now employed for the rectifying purpose, but it is possible such experiments would give very interesting results.

Dr. C. P. STEINMETZ: I may add that with the mercury arc complete rectification takes place if both electrodes are symmetrical. It is curious to note in certain ranges of voltage, if both electrodes are absolutely symmetrical, both of mercury, the first spark decides the direction in which the arc rectifies. After a while, the arc may drop a half wave and then rectify in the opposite direction, etc. It is immaterial in which way it rectifies. After straying one-half wave it passes the current in this direction, and drops the half waves in the opposite direction, that is, it rectifies. It is possible these phenomena might appear here in Professor Lombardi's arcs also, but which electrode is positive is indeterminate, if the electrodes are symmetrical. If the electrodes are not symmetrical, there is a preponderance in one direction, making one electrode negative and the other positive.

CHAIRMAN LIEB: We will now hear Professor Nichols' paper on "Standards of Light."

Prof. NICHOLS: I will simply say that the paper which you have at your disposal is an attempt to gather together the physical characteristics and constants of all claimants which have been found most suitable for photometric purposes. There is nothing in the experiments described which calls for discussion, and nothing which needs further explanation. I will not even take your time to give an abstract of the paper, in view of the lateness of the hour. All who are interested in it may read it at their convenience.

STANDARDS OF LIGHT.

BY PROF. EDWARD L. NICHOLS, *Cornell University.*

The conditions demanded of a physical standard are very far from being fulfilled in the case of the existing standards of light. The standard should be suitable and convenient for the purposes for which it is to be used, capable of precise definition and reproducible; and it should if possible stand in some simple relationship to our absolute system of measurement. The history of the art of measuring shows that in the beginning standards are selected from familiar and easily accessible sources. The questions of accuracy and reproducibility come in later for consideration and that of relations to absolute systems last of all. Thus we have for primitive standards of length the foot, the hand, the pace, etc.; for standards of mass the pennyweight, the stone, etc.; for standards of liquid volume the drop, the teaspoonful and the cupful; as a standard of activity the horse power.

The fact that the candle is still, nominally at least, our standard of light indicates that in photometry we are still in an early stage of development. The persistence of this term in our nomenclature marks, as does the continued use of the word horse-power, as applied to engines, the natural conservatism of the race. The term *candle power* is at present, like *horse power*, a survival, but both are likely to persist for a very long time to come. We have however in photometry at last and forever abandoned the futile attempt to standardize the actual candle, although it still stands in law as a unit, and have turned our attention toward the establishment of units of light which fulfill more nearly the requirements of a scientific standard.

The development of standardization in photometry is following a somewhat different course from that which has taken place in electricity and in mechanics. In the case of the meter and the kilogram, which it was originally proposed to establish in terms of the dimensions of the earth, and the density of water, we have receded from the original standpoint and as a matter of convenience

content ourselves with making copies of certain prototypes which are known to fulfill only approximately the original definitions. Of our three fundamental electrical units the ohm alone seems likely to be maintained with strict relation to the c.g.s. units, while for the others we are inclined to the more convenient values obtained from the chemical equivalent of silver or the electromotive force of a standard cell, using such reduction factors as shall bring the volt and ampere into sufficiently close approximation to the absolute units.

In the case of the standard of light we are forced by circumstances to content ourselves for the present with finding some reasonably reliable and practical unit. When we have found this it will perhaps be possible to establish the numerical factor by means of which to express it in terms of ergs of luminous energy per unit of time.

In the search for a practical standard of light the photometrician has before him the following possibilities:

(1) The use of a standard flame.

(2) The use of an incandescent body of a fixed temperature.

(3) The use of a luminescent body.

The numerous studies of luminous flames which have been made in the attempt to secure a suitable standard of light have shown that in order to secure even approximate uniformity it is necessary to have *a fuel of definite composition consumed under constant conditions.* Of the various candle, oil and gas flames proposed as standards in the past, none conform to these conditions. The futile struggle of a century of photometricians with candles of spermaceti, paraffin and stearine and the endeavors of the various expert commissions appointed for the purpose of determining the relations between the standard candles adopted and legalized in different countries have only served to demonstrate the worthlessness of the candle, whatever its composition and construction, as a standard of light.

The only fuel of strictly definite composition which it has been found possible to subject to constant conditions of combustion is amyl-acetate. The thorough and careful manner in which the lamp for burning this fuel introduced by the late Hefner-Alteneck has been developed is well known to all students of photometry. Thanks to the investigations of Liebenthal and to the work of the German Gas Commission and of the members of the Reichsanstalt at Charlottenburg, we know, with as great a degree of precision as

the nature of the subject will permit, the influence of flame height, of temperature, of atmospheric moisture, of the presence of carbon dioxide in the air, and of atmospheric pressure upon the illuminating power of its flame.

It has been found as the result of these investigations that when lamps constructed strictly of the prescribed dimensions and materials are used under normal conditions of atmospheric pressure, moisture, etc., the illuminating power is reproducible to within two per cent. This performance so far exceeds in uniformity that of other known available photometric standards,[1] that the Hefner unit has very properly been adopted by photometrists as the best primary standard in spite of that fact that the quality of the flame is such as to seriously interfere with satisfactory comparisons between it and the whiter and more brilliant sources of light used in modern illumination.

In view of the general acceptance of the Hefner lamp as the primary standard, in terms of which candle power is to be defined and by comparison with which secondary standards are to be calibrated, I have brought together for convenient reference the following data concerning this source of light.

Physical constants of the amyl-acetate flame.

In addition to the investigation of the effects of flame height upon the intensity of the Hefner lamp, the results of which are shown in Fig. 1, of moisture, see Fig. 2, and of the effect of the presence of carbon dioxide in the atmosphere upon the intensity of this source of light (Fig. 3); all of which are plotted from data published by Liebenthal,[2] we have a more precise knowledge of the physical constants relating to this flame than of any other source of light.

Koettgen[3] has compared the flame of the Hefner lamp spectrophotometrically with numerous other artificial sources of light, especially with various oil and gas flames. While the results are

1. A possible exception to this statement is the modified form of pentane lamp largely used by gas photometrists in the United States, for which a performance comparable to that of the Hefner lamp has been claimed. This source, however, in spite of the good accounts given of it and the superior whiteness of its flame, is open to objection, as a primary standard, on account of the indefinite character of the fuel employed.

2. Liebenthal. *Elektrotechnische Zeitschrift*, 1888, p. 204; ibid. 1895, p 655.

3. Koettgen. *Wied. Ann.*, LIII, p. 793.

strictly applicable only to the particular flame measured in each case and only approximately to other flames of the same type, the

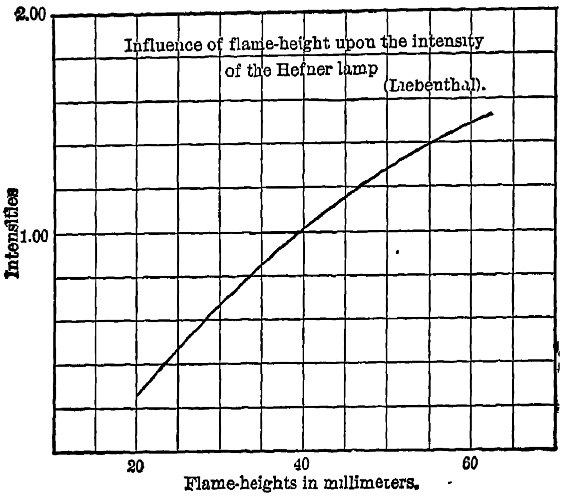


FIG. 1.

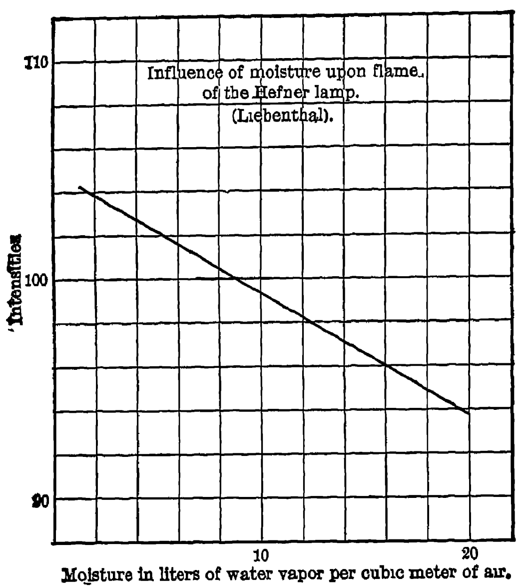


FIG. 2.

curves giving the relative distribution of intensities in their spectra are of interest since they describe as completely as the circumstances

will permit the color relations of such flames. Two such curves plotted from his tables are shown in Fig. 4. They are drawn in the usual manner with wave lengths as abscissae and the ratio of the intensities for each wave length of the spectrum divided by the

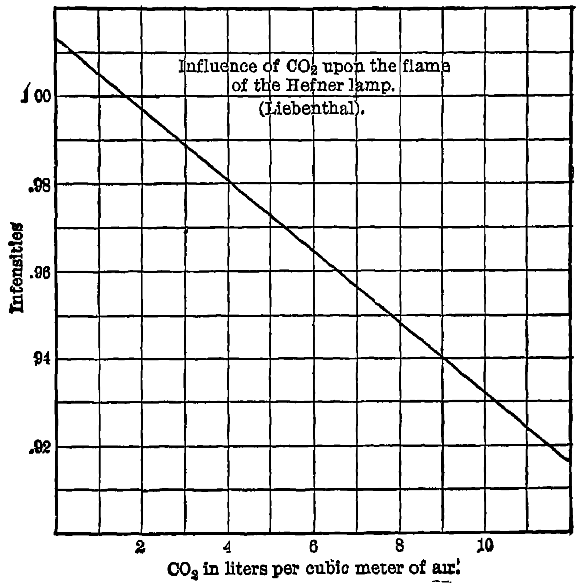


FIG. 3.

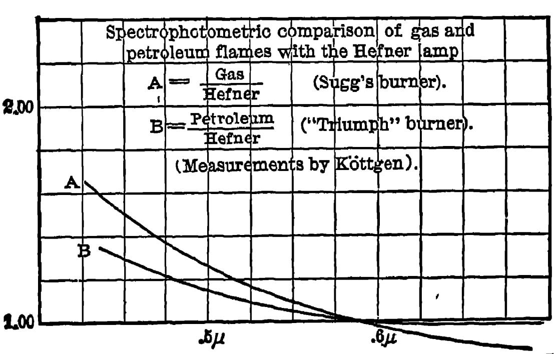


FIG. 4.

same ratio, for the region of the *D* line, as ordinates. It will be seen from these curves which refer respectively to an ordinary gas flame and the flame of a petroleum lamp, that the light of the Hefner lamp is relatively stronger in the red and weaker in the

violet than the ordinary sources of light used in artificial illumination; and that, consequently, we should expect to find that the temperature of this flame is lower than that of our ordinary oil or gas flames.

Knut Angström[4] in a recent paper has published data which define the physical constants of the Hefner flame in absolute measure. By means of a spectrobolometer he first explored the infra-red spectrum as far as 5μ. The resulting curve is of the general form which one would expect for a flame of this character. It shows the strong emission band due to CO_2 at 4.4μ and has its maximum, as is to be expected from the character of the spectrophotometric curves already given, at a greater wave length than is the case with other luminous flames. G. W. Stewart[5] has found the maximum for the candle at 1.25, for the ordinary gas flame at 1.13μ and for the acetylene flame at 1.05μ.

Angström[6] has likewise determined the radiant efficiency of the Hefner lamp. He assembled upon the face of the bolometer the entire energy of the spectrum of the amyl-acetate flame and observed the total radiation (Q). An opaque screen, which cut off all wave lengths greater than 0.76μ, was then interposed, and the remaining radiation (L), which constitutes the whole of the visible spectrum, was assembled upon the same bolometer, and measured. He finds for the ratio of these two quantities

$$L/Q = 0.009{,}6$$

where L is the luminous energy and Q the total energy of the flame.

The unit of illumination, the *lux* or *bougie-metre* has been defined as the illumination received from the Hefner lamp at a distance of one meter. By the use of his compensated pyr-heliometer Angström has succeeded in determining this quantity also in absolute measure. He finds for the total radiation corresponding to the lux,

$$Q = 0.000{,}021{,}5 \ \frac{\text{gram. cal.}}{\text{sec. cm}^2}.$$

From the value of L/Q already given it follows that the *luminous* radiation corresponding to the lux is

$$L = 20.6 \times 10^{-8} \ \frac{\text{gram. cal.}}{\text{sec. cm.}^2}.$$

4. Angström. *Physical Review*, Vol. XVII, p. 302.
5. Stewart, G. W. *Physical Review*, XV, p. 311.
6. Angstrom, *l. c.*

Tumlirz[7] has determined by a different method the value of the luminous radiation corresponding to the lux. He obtained a somewhat larger value than Angstrom but of the same order; viz.

$$L = 36.1 \times 10^{-8} \frac{\text{gram. cal.}}{\text{sec. cm}^2}.$$

In other words according to the determinations of Tumlirz a surface of one sq. cm. placed in the horizontal plane passing through the center of the flame of the Hefner lamp at a distance of one meter receives in one second an amount of light the energy equivalent of which is 3.61×10^{-9} gram-cal.

By pushing the opaque screen further and further into the luminous spectrum Angström found it possible to measure the energy L_λ of portions of the spectrum lying between the ultra violet and the position of the screen for a number of different settings of the latter. The quantity of energy measured in each case is

$$L_\lambda = \int_o^\lambda I_\lambda \, d\lambda$$

where λ is the wave length at the edge of the screen. Assuming the accuracy of Wien's formula,

$$I = C_1 \lambda^{-5} \varepsilon^{-\frac{c_2}{\lambda T}}$$

for the radiation of a black body, which for the wave lengths of the visible spectrum may be regarded as established, we have

$$\int_o^\lambda I_\lambda \, d\lambda = C_1 \int_o^\lambda \lambda^{-5} \varepsilon^{-\frac{c_2}{\lambda T}} d\lambda$$

in which, since T is a constant, it is possible to determine the constants by means of a series of observations of L_λ and to obtain the following expression for the distribution of intensities in the spectrum of the Hefner lamp.

$$I_\lambda = 0.0160 \, \lambda^{-5} \varepsilon^{-\frac{7.85}{\lambda}}.$$

The intensities given by this equation are represented in the curve (Fig. 5). This curve is very important because by means of it we are able to compute the corresponding intensities for any source of light which we have compared spectrophotometrically with the Hefner flame.

7. Tumlirz. *Wied. Ann.*, vol. XXXVIII, page 661.

In the above equation the constant 7.85 is equal to c_2/T of Wien's formula, and since Paschen and Wanner[8] have found c_2 in the case of a black body to be 14,440, the temperature of the Hefner flame may be computed. Angström finds this temperature to be 1830° (abs)=1557°C, a value which is quite consistent with the temperature of the candle flame computed by Lummer and Pringsheim[9] (1960° (abs)=1687°C), with my direct measurements,[10] which gave for the temperature of the candle 1670°C and with the more recent estimates of G. W. Stewart.[11]

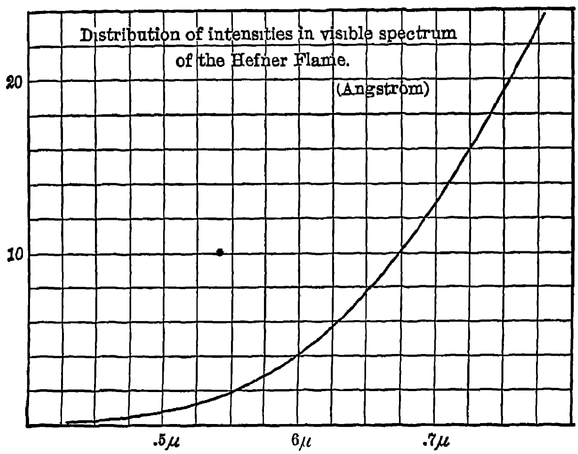


FIG. 5.

The temperature of the amyl-acetate flame may likewise be estimated, by means of Paschen's law, from the position of the maximum of the curve for the distribution of energy in the spectrum. In the absence of the data to reduce Angström's curve, which was plotted with circle readings as abscissae, to the form necessary to fix the precise wave length of the maximum, Mr. W. W. Coblentz has had the kindness to repeat these measurements for presentation in this paper. He employed the reflecting spectrophotometer, with rock-salt prism and Nichols radiometer, which has been used by him for the past three years in his investigations upon infra-red spectra.

8. Paschen and Wanner. *Berliner Sitzungsberichte*, 1899.
9. Lummer and Pringsheim. *Verhandlungen* d. Deutschen Phys. Ges., III, p. 37, 1901.
10. Nichols. *Physical Review*, vol. X, page 248.
11. Stewart, G. W. *Physical Review*, vol. XV, page 313.

The resulting curve, corrected for slit widths, is shown in Fig. 6. The maximum falls at 1.52μ and the temperature of the flame therefore, or more strictly the temperature of a black body emitting similar radiation, calculated from Paschen's equation, is 1934° (abs) or 1661°C.

This value is about one hundred degrees higher than that obtained by Angstrom from the relations already described, but, as will be pointed out later, Paschen's equation, using the constant 2940, gives values, for all flames, considerably above those deduced from direct measurements.

I have considered these results of Angström and others at length because although they do not at present apply immediately to the problems of simple photometry they place at least one source of

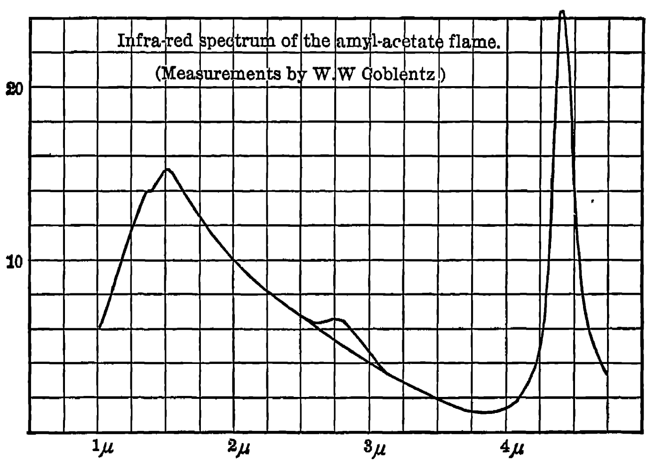


FIG. 6.

light in definite relations to our absolute systems of measurement, afford us the data long desired for bringing all other spectrophotometric determinations, by means of comparisons with the Hefner lamp, into the same condition, and afford a starting point from which we may be able, ultimately, to define our units of light and of illumination in terms of the absolute system.

Physical constants of the acetylene flame

Another fuel of definite composition which, were it possible to control the conditions of combustion, would afford a standard of light superior on account of the intensity and whiteness of the

light which it emits to the amyl-acetate flame and to all other flames hitherto used in photometry is acetylene. It has thus far been found impossible to devise a reproducible acetylene standard or even to produce a form of burner which will remain of even approximately constant intensity from day to day. Studies of the acetylene flame have however brought out very definitely the nature of the difficulties to be overcome and in view of the peculiarly desirable qualities of this source of light for photometric purposes the following summary of results may be of interest.

Acetylene is so rich in carbon that in order to produce a smokeless flame it is necessary to mix with the gas a certain proportion of air. All existing acetylene burners are modifications of the Bunsen type and as the proportion of air increases the flame goes over from the smoky form to that of the non-luminous Bunsen flame passing by intermediate stages through a maximum of luminous intensity. The brightness of the flame and its color depend upon the amount of air which is mixed with the acetylene and small changes in this mixture produce considerable variations both in the intensity and in the quality of the light. Burners designed to be of the same candle power even when supplied from the same gas holder and operated under conditions as nearly identical as practicable as regards gas pressure, etc., exhibit considerable differences in intensity and color and these relative differences vary from time to time to an extent which renders the ordinary form of acetylene burner unsuitable for use in accurate photometry.

The following measurements of the radiant efficiency of the acetylene flame will serve to illustrate the nature of the fluctuations to which flames from burners of the ordinary type are subject.

TABLE.

Radiant efficiency of the acetylene flame.

L/Q	=	.056	(Angstrom)[12]
"	"	.033	(Nichols and Coblentz)[13]
"	"	.040	" " "
"	"	.040	(From a curve by G. W. Stewart)

These results with the exception of that of Angstròm were obtained by plotting the curve of energy for the spectrum of the

12. Angström *Astrophysical Journal,* XV, p. 223, 1902.
13. Nichols and Coblentz *Physical Review,* XVII, p. 267, 1903.

flame and comparing the luminous with the total area by integration of the same. A study of these curves reveals the nature of the phenomena upon which the fluctuations in intensity and quality in the acetylene flame depend and the chief difficulty which must be overcome in the construction of a strictly reproducible standard of the acetylene type.

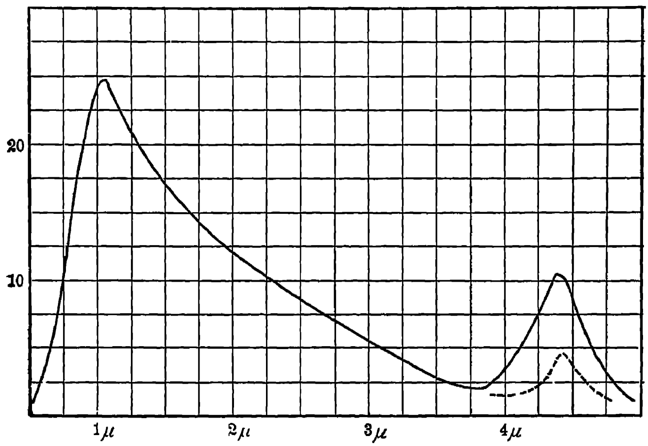


FIG. 7.—INFRA-RED SPECTRUM OF AN ACETYLENE FLAME (FROM MEASUREMENTS OF COBLANTZ).

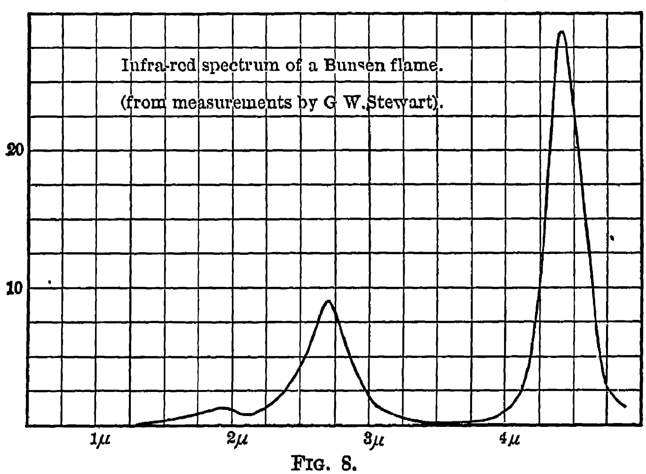


FIG. 8.

The characteristic feature of the energy curve of the acetylene flame is the emission band having its maximum at 4.4μ, (see Fig. 7). In non-luminous flames of the Bunsen type this band forms the most important part of the infra-red spectrum as may be seen from the curve in Fig. 8 which is reproduced from measurements

made by G. W. Stewart.[14] As the air supplied to an acetylene flame increases this band becomes more prominent and the radiant efficiency falls off. The growth of the band adds to the area of the non-luminous portion of the curve, as compared with the total area, and this change in the conditions of combustion affects, as has already been stated, both the quantity and the quality of the light from the flame. That the intensity of the CO_2 band in the infra-red spectrum of the acetylene flame fluctuates through a considerable range is shown in Fig. 9, in which measurements of the band in the spectrum of the light from one and the same burner observed on four occasions are plotted.

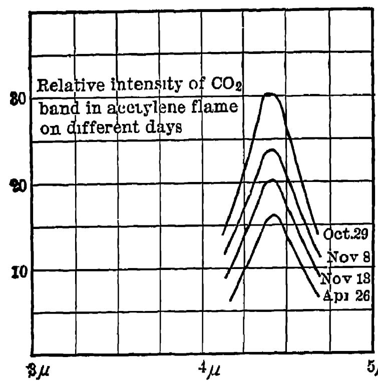


FIG. 9.

The curve of Oct. 29 corresponds to conditions of combustion under which the radiant efficiency was .033; that of Nov. 8 to an efficiency of .040.

Were it possible to burn the proper mixture of acetylene and air in a burner, the dimensions of which like those of the Hefner lamp were sufficiently great to admit of accurate workmanship, there is every reason to suppose that this source of light would show the uniformity desired in a standard. The mixture is, however, violently explosive and in order to keep the flame from striking back the gas orifice must be very small. Not only is it impracticable to make burners with such small openings which will give strictly the same size and intensity of flame but in a given burner the orifice is subject to partial clogging. The result is a variation in the proportion of acetylene to air and a change in size and intensity of the flame.

14. Stewart, G. W. *Physical Review*, vol. XIII, p. 272, 1901.

Experiments have been made by C. H. Sharp upon the combustion of pure acetylene in a mantle of oxygen using a burner in which a single cylindrical gas orifice was surrounded by an annular opening for the oxygen; an arrangement similar to that of the ordinary blast lamp excepting that the gas is introduced into the center of the flame. This flame is of extraordinary brilliancy but its excessive sensitiveness to changes of pressure and its instability renders it altogether unfit for use in photometry. That it is relatively much richer in the blue and violet may be seen from the curve in Fig. 10 which is plotted from Sharp's data (Physical Review, Vol. IX, p. 179).

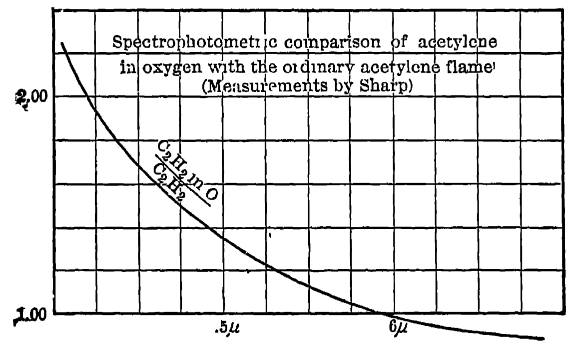


FIG. 10.

L. W. Hartman[15] has made a photometric study of mixtures of acetylene and hydrogen burned in air. When a burner without air vents and consisting simply of a circular orifice through a brass tip was used it was found that the intensity of the flame increased with the percentage of acetylene, and reached a maximum, as shown in Fig. 11, at a point corresponding nearly to a mixture of equal parts of the two gases. Further additions of acetylene to the mixture resulted in an increasingly imperfect combustion and a gradual falling off in the brightness of the flame.

The hydrogen-acetylene flame is whiter than that of pure acetylene burning in air; the former flame being relatively weaker at the red and stronger at the violet end of the spectrum as shown in Fig. 12 which contains a curve of relative intensities plotted from measurements by Hartman. There are certain difficulties connected with the use of an acetylene-hydrogen mixture. The mixed

15. Hartman, L. W. *Physical Review*, vol. IX, p. 176.

gas cannot for example be stored in ordinary gasometers over water because the two gases are so unequally absorbed by that liquid that the mixture on standing will rapidly become poorer in acetylene up to the point where the water is saturated with that gas.

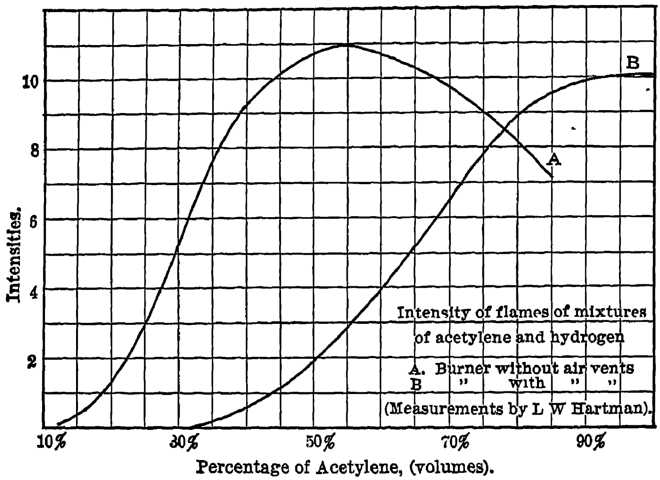


FIG. 11.

Subsequently the mixture will vary in its proportions with changes of pressure as the water with every change of condition absorbs or gives off acetylene to the mixture. This difficulty is not how-

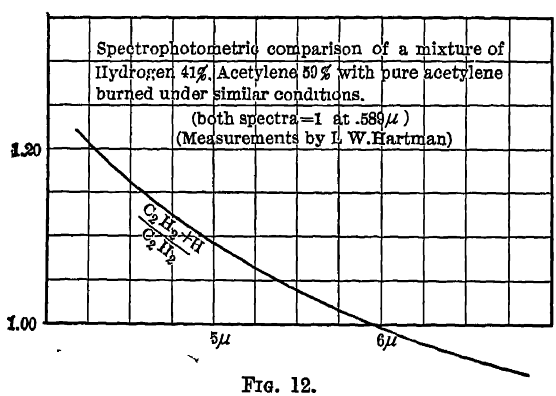


FIG. 12.

ever fatal to the use of such a combination provided a mixture of these two gases can be found which is capable of perfect combustion in a burner that is strictly reproducible in its dimensions and construction.

With a burner consisting of a single cylindrical jet of 1 mm diameter it is possible without the use of air ducts to produce a quiet steady flame of excellent brightness and color provided the burner be supplied by means of a T from separate gasometers containing hydrogen and acetylene. By igniting the hydrogen first and then turning on the acetylene gradually by means of a proper valve a suitable mixture is readily obtained. The flame, which is of a tall conical form, is perfectly symmetrical and has a well-defined luminous tip. It can be used either with the flame gauge, as in the Hefner lamp, or with a metallic screen similar to that employed in a Harcourt pentane standard. The size of the orifice in such a burner is sufficient to permit of reasonable accuracy in the construction of the standard lamp and the problem

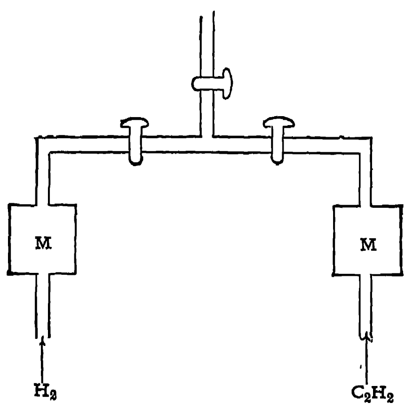


FIG. 13.—MIXING DEVICE FOR HYDROGEN-ACETYLENE FLAME.

of maintaining a constant admixture of the gases may be solved by the use of two similar experimental gasmeters M, M, provided with a rapidly moving index hand for the determination of the rate of flow. By selecting a mixture which corresponds to the crest of Curve A (Fig. 11) the condition of minimum sensitiveness to variations in the proportions of the two gases can be secured. The arrangement proposed is shown diagrammatically in Fig. 13. Only rough preliminary trials with this apparatus have thus far been attempted but there is every reason to believe that with the same attention to details which have been employed in the development of the Hefner lamp an excellent hydrogen-acetylene flame can be secured. The somewhat complicated and cumbersome nature of

this apparatus would preclude its employment for general photometric purposes but since a primary standard is required only for the purpose of calibrating incandescent lamps to be used as working standards this objection is of minor importance.

The superiority of the acetylene flame over the Hefner finds graphical expression in Fig. 14 which gives in the usual manner the spectrophotometric ratio throughout the spectrum. The preponderance of the shorter wave lengths is indeed excessive so far as photometry of ordinary gas and oil flames are concerned, the color difference between such flames and acetylene being about as great on the one side as the difference between them and the Hefner flame is on the other. For use in comparison with the more modern illuminants of high efficiency such as the Nernst lamp, etc., however, the distribution of color in the acetylene flame is such as to reduce the color difference to a minimum.

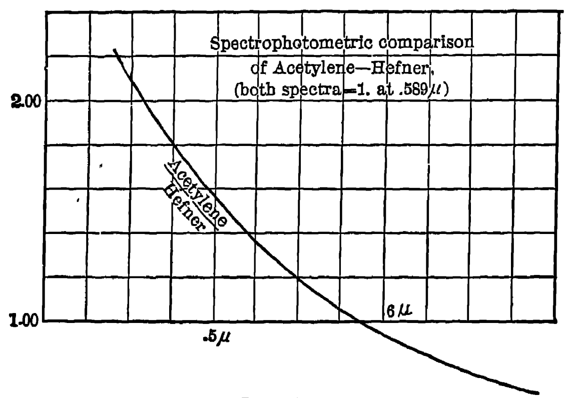


FIG. 14.

Mr. Hartman has also measured the intensity of the ordinary acetylene flame at various pressures. His results, which are given graphically in Fig. 15, show a nearly linear relation.

Spectrophotometric studies indicate for the acetylene flame a temperature considerably above that of the ordinary gas flame.

I have found its temperature by direct measurement to be approximately 2173° (abs) or 1900°C as against 2053° (abs) = 1780°C for the ordinary gas flame and 1943° (abs) = 1670°C for the hottest part of the flame of the common candle. The temperature of the acetylene flame computed by means of Paschen's

law from the position of the maximum of the energy curve give somewhat higher values. G. W. Stewart,[16] finds this maximum to lie at 1.05μ from which we obtain for the "black" temperature corresponding to the acetylene flame 2940° (abs) or 2527°C.

The constant A in Paschen's formula has been determined for the ideal "black" body, but the precise relation between the "black" temperature computed by means of it and the actual temperature of the flame is as yet an open question. Stewart in the article just cited has shown that if we adopt the value $A = 2282$, the temperatures of the candle, the ordinary gas flame and the acetylene flame computed from the position of the maximum of their respective energy curves agree with the temperatures obtained by direct measurement.

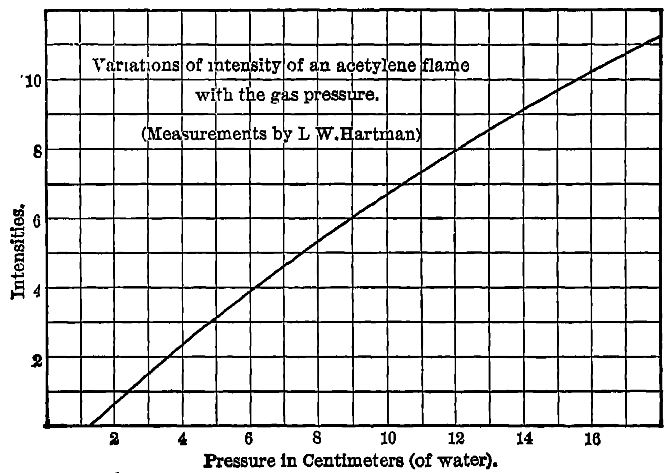


FIG. 15.

The distribution of intensities in the visible spectrum of the acetylene flame is a matter of great interest to those who apply this sort of light in spectroscopy and spectrophotometric measurements. The observations recorded by Stewart[17] in Table I of his paper on the distribution of energy in the acetylene flame, when properly corrected for variations of slit width, afford the data by means of which to construct the desired curve. It is interesting to compare this curve (see Fig. 16) with that in Fig. 5 which

16. Stewart, G. W. *Physical Review*, vol. XV, p. 311.
17. Stewart, G. W. *Physical Review*, vol. XIII, p. 268.

gives us the corresponding data for the Hefner flame as determined by Angström in an entirely different manner.

By making use of the ratio of relative intensities in these two sources of light, given in Fig. 14, and the curve in Fig. 5 it is possible to compute from quite independent data the distribution of intensities in the visible spectrum of the acetylene flame. The points marked with an X in Fig. 16 indicate the value of the ordinates thus obtained in several regions of the spectrum. Since these points lie along the curve plotted from Stewart's measurements we have an admirable check upon the accuracy of these two methods and of the spectrophotometric measurements recorded in Fig. 14. This agreement is the more remarkable and satisfactory since measurements made by three different observers are involved.

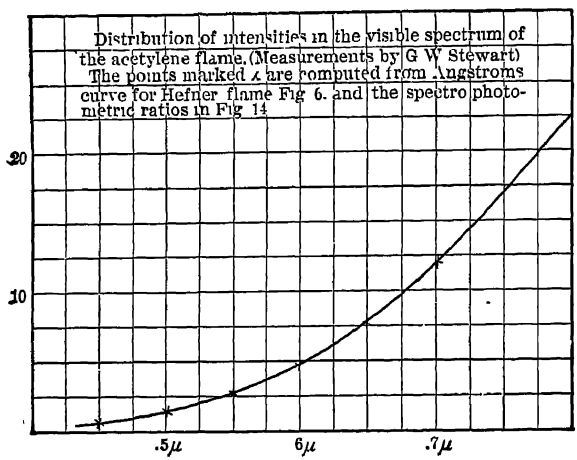


FIG. 16.

Incandescent solids as standards of light.

The use of an incandescent solid as a primary light standard would at first sight appear to offer many advantages over any possible flame standard, but the difficulties have thus far been insuperable. The three types of light source available for such a purpose are the incandescent mantle of the Welsbach type, the electric glow lamp, and the Nernst lamp. The difficulties to be considered in the case of the first are three: (1) That of producing mantles of uniform composition; (2) that of maintaining the same at a constant temperature by means of a flame of the

Bunsen type; (3) the progressive deterioration in the light-giving power of such mantles as the result of the exposure to high temperatures. Since the performance of an incandescent mantle depends in great measure upon the admixture of certain oxides of the rare earths to the thorium oxide which forms the principal constituent the satisfactory standardization of the material would probably be found impracticable. Burners of the Welsbach type are, moreover, notably sensitive to the well nigh uncontrollable fluctuations in the character of the heating flame and such mantles show deterioration with time as a result of the disintegration of the fabric, whereby the area of the incandescent surface is gradually diminished. The changes due to this cause alone have been estimated to be about 50% during the normal life of such a mantle. The marked change in the color of the light of the incandescent mantle with age is probably due to the fact that this disintegration affects the various components unequally so that the composition of the glowing body is continually changing.

The glow lamp offers a more promising field for development but the makers of such lamps have not as yet been able to furnish a filament which will meet the conditions of reproducibility. The admirable performance of incandescent lamps as calibrated secondary standards however suggests possibilities in the way of the development of a primary standard of this type. Should the use of carbon be found impracticable it is possible that the new osmium lamp may show greater constancy of performance. The use of a filament of the Nernst type as a primary standard of light is something which has not as yet been seriously considered and it certainly offers a fruitful field for investigation.

Numerous suggestions for a photometric standard have been made of which nothing has been said in this paper. Of these the Violle platinum standard, the use of the light from the crater of the arc and others have been tried and found unmanageable. The use of a phosphorescent surface has been proposed, but even were such sources of light of sufficient constancy the luminous intensity of all known phosphorescent materials is so feeble that they could be employed only in certain exceptional cases.

While it is probable that the future will see the development of a satisfactory primary standard based upon the electrical heating to incandescence of carbon or of some metallic oxide, the immediate basis for standardization of artificial light sources lies in

the use of a primary standard consisting of a flame standard and the preparation of calibrated incandescent lamps as secondary standards of light. Such lamps may in the present state of the art be made to agree with each other with all necessary exactness. While the absolute definable value of such standards can for the present be considered as exact only within the limits of reproducibility of a flame standard such as the Hefner lamp, the actual agreement of the standards existing in those laboratories in which photometric work is based upon the Hefner unit appears to be much closer than the performance of the amyl-acetate lamp, would lead us to anticipate.

A set of six 16-cp lamps calibrated in New York were, for example, recently taken abroad for comparison. The average result reported by the Reichsanstalt, according to Dr. Sharp to whom I owe the data, was 15.95 British candles (the ratio 1 Hefner = .88 B. C. P being used). When tested in New York after their return they averaged 15.96 candle-power, and subsequent measurements of them at the National Bureau of Standards gave 15.92 candle-power. The performance of the individual lamps may be seen from the following table:

INTENSITY IN BRITISH STANDARD CANDLES OF SIX CALIBRATED INCANDESCENT LAMPS.

	Values at Reichsanstalt. (1 Hefner = .88 cp)	Values at Electrical Testing Laboratories after return.	Values at National Bureau of Standards.
	15.87 cp.	15.85 cp.	15.85 cp.
	15.95	16.04	15.90
	15.88	15.99	15.80
	16.00	15.99	15.95
	15.96	15.89	16.00
	16.05	16.01	16.00
Average	15.95	15.96	15.92

Comparison with secondary standards purporting to represent the British standard candle, but not based upon the Hefner unit, gave, it may be added, no such satisfactory agreement.

I present these figures solely for the purpose of substantiating the statement just made, that the calibrated incandescent lamp is capable of very satisfactory performance as a secondary standard. By the constant interchange and comparison of results between the

various establishments engaged in the production of such lamps it should be possible to maintain in future the excellent agreement of working standards which appears to have been already attained, and thus to meet the demands of industrial photometry during the period which must elapse before science, through further research, is prepared to offer the practical photometrician something more completely adapted to his needs.

DISCUSSION.

CHAIRMAN LIEB: I do not think we can take any time for discussion. The hour is very late and we will therefore adjourn the Section to meet promptly at half-past nine to-morrow morning.

The Section then adjourned, to meet at 9:30 o'clock on Friday morning.

FRIDAY MORNING SESSION, SEPTEMBER 16.

Chairman Lieb called the meeting to order at 9 30 a. m.

CHAIRMAN LIEB: The first paper this morning will be that on "Storage Batteries," by Mr. Gerhard Goettling, of the Boston Edison Company.

Mr. Goettling presented his paper.

STORAGE BATTERIES AS AN ADJUNCT TO CENTRAL STATION EQUIPMENT.

BY GERHARD GOETTLING, *Delegate of the Association of Edison Illuminating Companies.*

In presenting this paper on Storage Batteries, I shall attempt to give a brief outline of the present methods of installation and operation of Storage Batteries as practiced by the Edison Companies in the United States.

DEVELOPMENT.

Only a few years ago, most of the station managers knew storage batteries only by name, and were strongly averse to their use as being unnecessary and complicated; but gradually they found that the complication brought into their plants by the new element was far outweighed by the advantages and the reliability which the use of batteries offers.

I might say, that the present opinion is, that any direct current system, and also alternating current systems, operating with converting sub-stations, cannot give reliable service without the aid of batteries.

This fact is best shown by the marvelous growth of the application of batteries to central station distribution in the last 10 years. Following the installation of a comparatively small battery of English manufacture in the 53rd St. station of the New York Edison Company, the Boston Edison Company made the first decided step in advance, by installing, in 1894, a battery of German manufacture of much larger capacity. Since then, the use of batteries has increased greatly, so that at the present time, there are some 98 batteries installed — 30 being located in generating stations, having a capacity of 23,036 kw-hours and 68 in substations, with a capacity of 101,206 kw-hours.

The following Table shows the yearly increase in number and capacity:

TABLE I.—KILOWATT HOUR CAPACITY OF CENTRAL STATION BATTERIES.

Year	Generating stations.		Sub-stations.		Exciter batteries.		Total	
	No	Capacity KW-H	No	Capacity KW-H	No	Capacity KW-H	No	Capacity KW-H
1894 .	2	938	..	. ..	..	......	2	938
1895 . .	4	1,233	1	2,738	..	......	5	3,971
1896 ..	5	2,968	6	9,375	..	......	11	12,343
1897 ..	7	6,403	10	14,043	.	.. ...	17	20,449
1898	8	7,560	15	22,175	1	309	24	30 044
1899 ..	12	12,342	23	35,212	1	309	36	47,863
1900 ...	13	12,392	36	59,513	1	309	50	72,214
1901 ...	15	13,891	42	67,296	2	399	59	81,586
1902	19	19,398	47	75,117	2	399	68	94,914
1903.	22	21,695	63	94,475	5	730	90	116,900
1904....	22	21,695	68	101,206	8	1,341	98	124,242

The table shows during the last three years very little increase in the generating-station batteries. This is due to the modern tendency of companies to concentrate their generating plants in very few, but large, generating stations for alternating current, where batteries are used only for the excitation, as indicated by the increase in exciter batteries. This concentration necessitates numerous substations for distribution, and these substations are generally equipped with batteries, as is also indicated by the increase of substation batteries.

That the combination of large high-tension alternating-current generating plants and direct-current substations is not found to be reliable without the aid of batteries, is shown by the practice of most of the large companies. For instance, in New York, Chicago, Boston, Brooklyn and San Francisco, where about 75% of the total output of 170,000 kilowatts is generated as alternating current, 60 batteries are in operation, with a total capacity of 84,000 kw-hours; that is, two-thirds of the total given in Table I.

It is also worthy of note that practically all of the batteries in use in America in central-station service have been furnished by one manufacturing concern. A careful investigation shows that over 95% of the total storage-battery capacity in this service has been furnished by this one concern.

Construction of Batteries and Battery Rooms.

The battery room should be located as near the switchboard room as possible. This is especially advisable, so that the connections between battery and switchboard may be short, and the loss in voltage reduced to a minimum. It also facilitates the inspection of the batteries.

The battery room must be large enough to receive the battery without crowding the cells too much together. Taking the base area covered by a single tank as a basis, the space occupied by the tanks should not be greater than one-half the floor area. There are some battery rooms where the tanks cover more than 50% of the floor space, but the results show that the distance between the tanks is too small, and the aisles between the different rows of cells are so narrow, that any repair work on the battery is rendered difficult and expensive, besides making it very inconvenient to keep the battery room clean and dry.

The floor of the battery room must first be strong enough to support the battery with the tanks completely filled with plates, and, secondly, it must be acid-proof, especially in modern fire-proof buildings of brick and iron construction.

To protect the flooring from acid, two kinds of covering, brick and concrete, have been in use. The former has been found most satisfactory and is now considered as standard construction. (Fig. 1.)

This covering has, as a base, a layer of 6 ins. of concrete. On top of the concrete is put a thin layer of sand, about $\frac{1}{8}$ in. in which the bricks are laid. The common vitrified brick, 9 ins. by 4 ins. by $2\frac{1}{2}$ ins. or a special size 10 ins. square by 2 ins. thick is in use for this purpose. The bricks are laid $\frac{1}{4}$ in. to $\frac{3}{8}$ in. apart, leaving some space for grouting them with hot pitch. If the pitch becomes brittle when cooled, a small amount of tallow should be mixed with it before use. In pouring the pitch between the bricks, care must be taken to fill the space entirely, but at the same time not to cover the surface of the bricks. If too much sand or pitch is used, there is danger of settling, throwing the tanks out of alignment.

The second construction consists of several layers of tar paper or other waterproof material. On top of this waterproofing are laid 6 ins. of concrete, and the surface of this concrete made level and smooth. In some cases, the base of the flooring is first covered with 3 ins. of concrete, and then waterproofing put on, and on top

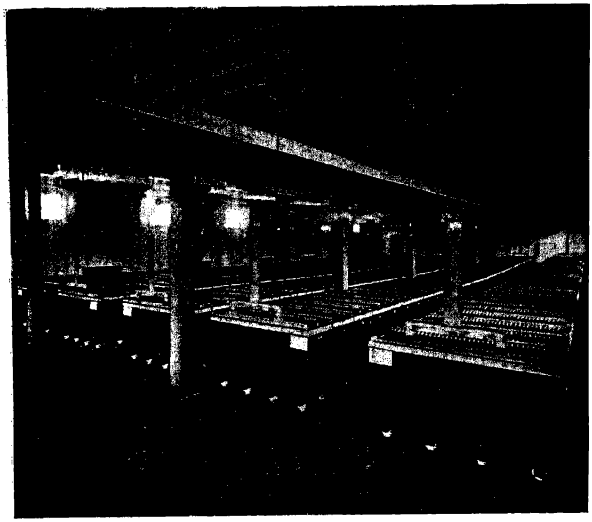


Fig. 1.— Battery room.

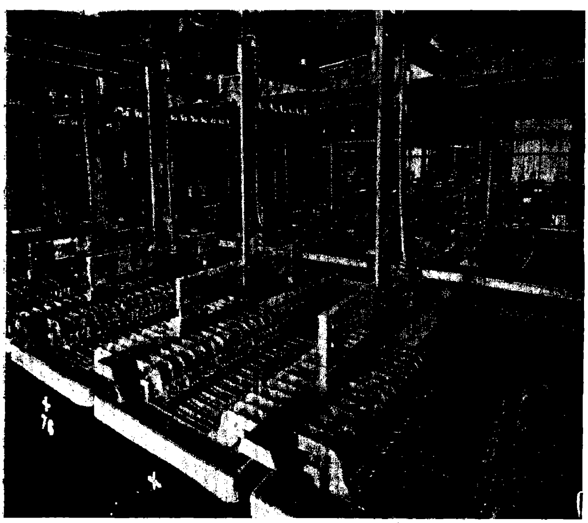


Fig. 2.— Battery room.

of this another layer of 3-in. concrete. Both methods have given satisfactory results. In any case it is necessary to carry the tar paper next to the walls 8 to 12 ins. above the level of the floor, to avoid the danger of acid leaking through the cracks between the concrete and walls. Sheet-lead is also successfully used.

On top of the concrete floor is sometimes put a thin layer of cement. The cement makes a smoother finish but has the disadvantage of being more easily attacked by the acid. Experience has shown that, contrary to the general opinion, the concrete is very slightly affected by the acid, due to the fact that the acid coming in contact with the concrete is neutralized in a short time. Actual tests have shown that 1 lb. concrete of the usual mixture, having a specific gravity of about 4.2, neutralized 0.48 lbs. of H_2SO_4. When we apply these figures to actual conditions, we find that the amount of acid which is lost per year by spray can corrode less than $\frac{1}{8}$ in. of the surface of the concrete. This theoretical result agrees fairly well with experience, which shows that a long term of years is necessary before the thickness of the concrete is diminished to any appreciable amount.

The vitrified brick floor has the advantage that it will withstand the action of the acid far better than the concrete floor. But if sufficient care is taken to keep the battery room clean at all times, as ought to be done in all cases, especially when the floor is washed at regular intervals with a weak solution of carbonate of soda, the concrete floor will give fairly satisfactory results.

Every battery room ought to be provided with proper drainage of the floor, so that it can from time to time be flushed with water. The best method is to give the floor from the center of each row of cells a slope toward the aisles, so that there will be no possibility of any acid or water remaining underneath the tanks.

Iron columns and pipes in battery rooms are best protected by encasing them with expanded metal work, upon which a coating of plaster is placed. This, if kept well coated with a good lead paint, will prove a satisfactory way of protecting all iron-work. As a further precaution, the iron columns must be protected at their base against attack by the acid. Satisfactory results have been obtained by covering the column at the base with sheet lead to a height of one foot above the level of the floor, soldering the sheet lead at the seams together, so that it forms a uniform cover, and filling the spaces between the iron and lead with hot pitch. Smaller portions of iron work can be treated only with a good

acid-proof paint, and inspected often enough to make sure that no iron sulphate is forming and liable to drop into the cells.

The copper bars can be protected either by a coating of lead, or by painting. The lead coating is accomplished by a process similar to galvanizing iron, and has proved fairly satisfactory, but it has the disadvantage that, if once attacked by the acid, it cannot be repaired without dismantling, and painting must then be resorted to. Therefore, there is some question whether it is necessary to go to the expense of lead coating the copperwork, if paint can produce a satisfactory result.

Special attention must be given to the connection between the copper bars. The nuts of the bolts at these points are very seldom sufficiently protected by simply painting them, so, as an extra precaution against corrosion, the paint should be coated with vaseline, or, better still, a special type of bolts should be used, these being so constructed that on each end a lead cap can be screwed on. This lead cap is filled with vaseline, and, when in place, it covers the nut entirely and prevents any acid getting in contact with the nut.

The question of securing a good acid-proof paint has received special attention in the last few years, since the amount of copper in battery rooms to be kept in good order is very considerable, as can readily be seen from Fig. 2.

Today, probably the best paint which can be used has carbon for a base. This, however, cannot be used in all cases, as it takes some days to dry. For protecting metal work in battery rooms, it is very good. A special quality of black asphaltum paint is one of the best wood protectors, which dries quickly, and is found to be very satisfactory. A word of warning might be said about some kinds of metal oxide paints. It is claimed that the oxides in these paints will not be attacked by the fumes, but experience shows that they are transformed in a short time to sulphates, and the paint thus made valueless.

All battery rooms must be well ventilated. The best way is to provide a steady circulation of air through the same, by having an inlet for fresh air at one end of the battery room, generally located near the floor, and an outlet for the acid fumes at the farther end, near the ceiling. Too much draft must be avoided, as it tends to increase the evaporation from the cells.

When it is found impossible with natural draft to change the air in the battery room in reasonable time, an exhaust or blower-fan

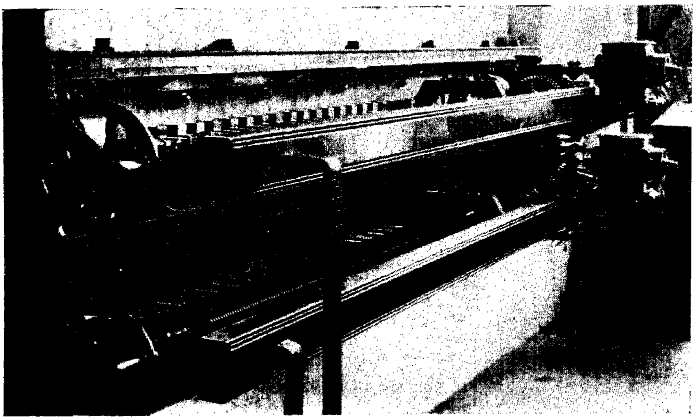


FIG. 4.— END-CELL CONTROL.

FIG. 5.— COVERED CELLS.

may be used. The former secures good ventilation, better than the latter, it having but the minor disadvantage that the fumes pass over the fan-blades, which, however, if made of phosphor-bronze or brass, are but slightly attacked. The motor for driving the fan is best located outside of the battery room, and connected with the fan by a rubber belt.

The outlet for the air must be so far away from the end-cell copper bars, so that the acid fumes do not have to pass between them. The copper bars rest on porcelain insulators, the insulators being mounted on wooden stringers, which are supported either by iron hangers from the ceiling or by iron pillars from the ground. (Fig. 2.)

The end-cell switches are either outside the battery room, or, when it is necessary to have them inside, a special partition is built around them so that the acid fumes have no access to them. As a rule, they are motor-controlled from the main switchboard, as shown in Fig. 4, which gives a good view of their standard construction.

It is best to install all cells in one tier, as a double-tier installation makes it difficult to inspect and fill the cells in the upper tier, and also the wooden tanks in the upper tier are easily damaged by the acid fumes rising from the lower cells, so that in the end the expenses for repairs are much higher than the saving gained eventually by this double-tier installation. Metal stands particularly, which, of course, would have to be used with large size cells, are very hard to protect, so that the metal sulphate formed on them will not get into the electrolyte.

The next point we have to consider is the insulation of the tanks. The former practice of installing with single insulation proved unsatisfactory. When a battery with this insulation has been in service for more than three or four years, troubles with leaky tanks have not been uncommon, so that at the present time double insulation is the standard.

This double insulation (Figs. 1 and 3) has been found to give most satisfactory results, as the upper insulator is far enough away from the floor to enable it to be kept perfectly clean and dry, and the additional height of the tanks from the floor gives a better circulation of air underneath them, which maintains a drier floor.

The wooden stringers between the porcelain insulators can run either lengthwise with the row of cells, or crosswise. The former arrangement is generally used with small sized tanks, using one set of stringers for 5 to 6 cells. For large sizes of tanks, it is found

advisable to have one set of stringers for each cell separately, with the stringer running crosswise to the row. This arrangement, besides giving a better circulation of air, and facilitating the inspection underneath the cells, makes also each cell independent from the other; a very important point in case of repairs.

In the construction of tanks, there are many points which should be considered to render the life of the tank as long as possible. The most acid-proof kind of lumber should be used, that is wood which contains a large amount of resin, like Georgia or yellow-pine. Of course, this kind of wood is hard to work on, as the tools become sticky by the resin, and must be often cleaned and sharpened, but the slight overexpense in manufacturing is well paid by the longer life that is gotten from these tanks.

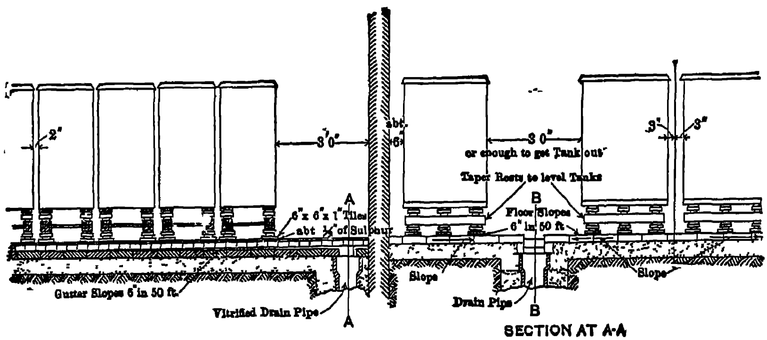
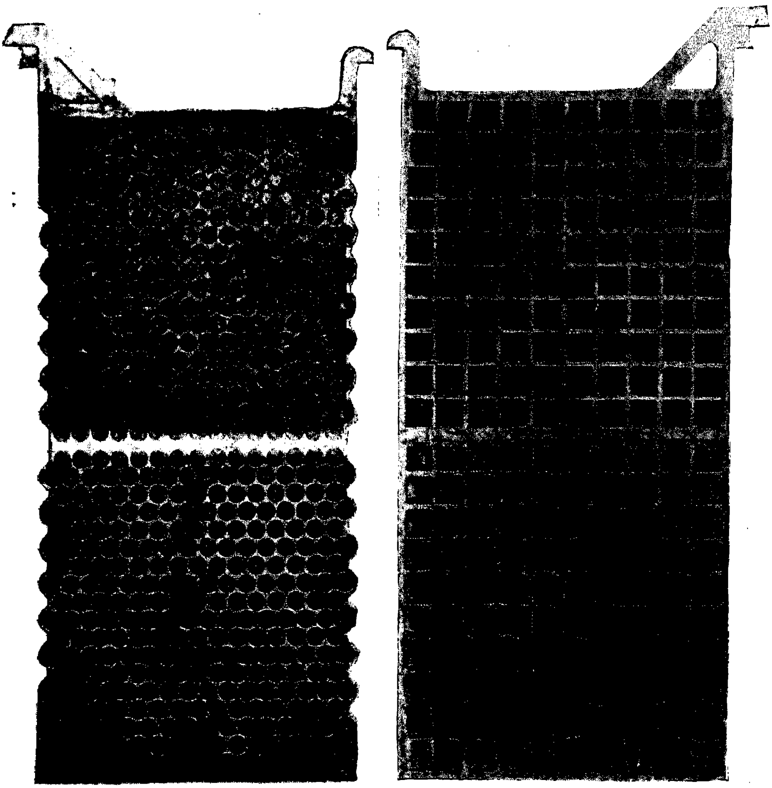


FIG. 3.— BATTERY ROOM.

Means should also be provided to keep the woodwork of the tank as dry as possible. This is done by giving the upper edge a slight slope to the inside of not more than 1 to 5. If the slope is made steeper, the edge will be too weak and easily break off when the tank is in service. The lead lining of the tank generally overlaps the upper edge on the outside for about 2 ins. By putting small wooden strips underneath this overlapping, the lower edge of the lead is kept about ½ in. away from the woodwork of the tank, so that any acid dripping from the edge does not run down along the wood. The former kind of plain tanks has been abandoned in favor of the panelled form, the latter being more rigid and giving better insurance against breakage on account of the warping of the wood. Between the cells in each row are put small porcelain insulators, which insure uniform distance between the cells, and also prevent the walls of the tanks from bulging out. For the latter reason also



Figs. 6 and 7.— Storage battery plates.

the outside wall of the tanks at the end of each row is reinforced by lead-coated iron rods, as shown in some cells in Fig. 1.

Another improvement in tanks with the point in view of reducing the operating cost of the batteries, is the increased amount of space at the bottom of the tank for the collection of the accumulation incident to the gradual wear of the positive plates. This space is now made of such a depth that it will contain all the sediment that is precipitated throughout the entire life of these plates, so that cleaning is only necessary at such times as plate renewals are required.

The battery plates, both positive and negative, as now furnished, show great improvements over those of previous years. Those most generally installed by the leading company are of the "Manchester" type for the positives (Fig. 6) and of what is known as the "Box" plate for the negatives. (Fig. 7.)

The positive consists of a rigid conducting support, holding in place soft lead formed into small buttons of coiled ribbon, with corrugated surfaces, these buttons extending slightly beyond the surface of the hard metal support, or grid, as it is technically called. These plates have been found to stand very satisfactorily the excessive demands that the storage battery is called upon to meet. The development in the negative plate has kept pace with that of the positive plate. The negative plate now consists of a hard metal supporting gird, in which the various sections of active material are securely held in place by means of a thin covering of perforated sheet lead. The advantage of this plate over all other types lies in its strong mechanical construction, in its greatly increased life, and its ability to maintain its capacity throughout a long period of use.

A still further development, and a most important one, is the substitution of thin wooden diaphragms between the plates as separators, in place of the glass tubes heretofore generally used. This new type of separator is superior, in that it effectively prevents any possibility of short circuits forming between the plates, thus keeping the cells in uniform condition, so that the amount of work in operating the battery is reduced materially, and the proper relation of charge to discharge maintained more economically — all of these features combining to effect a very considerable increase in the life of the plates.

Operation.

Among the numerous functions performed by the storage battery in modern lighting and power distribution systems are:

(1.) Supplying current for the peak of the load, both at the generating station and the substations, current so furnished being regained at the time of light loads, so that the load-factor is placed on a most economical basis.

(2.) Regulating or equalizing the pressure due to sudden fluctuations in the load.

(3.) Carrying the whole load when there is interruption in the service from the generating station, or locally, when the translating or transmitting service in the substation is in trouble.

(4.) Carrying the entire load, when it is so light that it is uneconomical to run the generating apparatus.

(5.) As a reserve for preventing interruptions in the exciter circuit in alternating generating systems, and for quickly starting up alternating-current motor-driven exciters.

All these features except (5) are well known, so that it is necessary only to add a few words about the exciter batteries, their introduction being a comparatively new one, but of the utmost importance for alternating-current generating stations.

In former times, where each alternating-current generator had its own exciter, a trouble in the exciter affected only its own generator, leaving the rest of the system intact, but with the present practice of uniting all exciters on one common bus, which in turn feeds the fields of all generators, it will readily be seen that trouble in the exciter system will affect the whole station with serious results. Therefore, it is necessary to keep the exciter bus at all times, and under all circumstances, alive, and at the proper voltage. The present sources of supply for the exciter bus are a set of motor-driven generators, with one or more steam-driven exciters as reserve. The steam-driven exciters need some time for starting, and are, therefore, not able to replace a motor exciter immediately, as is essential in case of emergency.

It is therefore important to have an additional supply of current to the exciter bus, which will work instantaneously. A feeder run from some other direct-current station to the exciter-bus may accomplish this, but in such a case it is either connected ready for service at all times, which makes complications in operating at the exciter-bus, as well as at the direct-current station; or, it is simply

ready for connection in case of trouble, and then much valuable time is lost by telephoning from the alternating to the direct-current station, and, therefore, the advantage of an instantaneous reserve is lost. There is, with such a feeder, always also the serious danger of its burning out at a critical moment.

All these troubles are avoided, when there is a storage battery in the station connected to the exciter-bus. The discharge current of this battery, at the one-hour rate, ought to be equal to the maximum excitation necessary at the exciter-bus, with 1.6 volts per cell pressure at the end of discharge.

When an accident happens, the battery will give immediately enough current to keep the excitation up, although the voltage may drop somewhat. Actual tests in New York have shown that the exciter-bus voltage can drop 11% without giving trouble in the system. Allowing that the whole motor-exciter system breaks down, that the battery is suddenly called upon for the one-hour rate of discharge, and that the operator has no time to adjust the end-cell switch, the drop from floating voltage will be well within the above limit. The end-cell switch must, of course, be motor driven and controlled by push-buttons; so it is the practice to have several push-buttons at different convenient places in the station, in order that the operator can work the end-cell slider, from any place wherever he may happen to be, at the time of the breakdown.

In order to keep the capacity at the highest point, an exciter-battery should be fully discharged once a week, and then immediately charged at the three-hour rate.

This high charging rate is advisable only for exciter batteries, where it is necessary to have the battery ready for service after a discharge as soon as possible. For lighting batteries, it is better to charge them at not higher than the five-hour rate.

The discharge rate of a battery naturally varies according to the service, and, under normal conditions, the rates prescribed by the manufacturer of the battery should be not exceeded. But in case of emergencies, it can be called upon for service at any high rate, without hesitation, provided care is exercised to restore it to normal condition with the least possible delay. The danger of harmful overdischarging does not exist in the case of Edison service, as the discharge is limited by the voltage on the main bus, which is not allowed to drop below certain limits.

In a very large degree, the obtaining of successful results from a battery is dependent both upon the quality and the specific gravity

of the electrolyte in the cell, and also upon the manner in which its changes in specific gravity, in the course of regular operation, are observed.

The presence of impurities, except within certain extremely small quantities, affects not only the immediate service of the battery, but also acts materially in reducing its life, so that it is most important that every possible precaution be observed in obtaining suitably pure electrolyte and maintaining it so.

The electrolyte must at all times be maintained at the proper level, so that the plates will not be exposed to the air. There is a gradual lowering of the level due to evaporation, especially during charge, and this should be regained by the addition of the purest water obtainable, preferably distilled water. In order to keep the evaporation down to a minimum, and also for the sake of protecting the exposed metal work about the battery from the effect of the acid fumes, which come off when the battery is being charged, some batteries are equipped with a covering over the cells, either in the form of a thin rubber sheet, or a glass plate. (Fig. 5.) This is not always to be recommended, on account of the difficulty of inspecting the cells; but the introduction of the wooden diaphragm separators has materially reduced the amount of inspection required and, therefore, the chief objection to covers.

As a medium for following the work that the battery is doing, and the condition of the various cells through the observation of its variations in specific gravity, the electrolyte is one of the most important factors in the routine of battery operation. It is, therefore, advisable to take, at certain periods, generally once a week, specific-gravity readings of each cell in the battery. Any cell which is not in normal condition will indicate it by abnormal specific gravity, and can thus be easily detected and promptly repaired. In my practice, in Boston, I have found it very convenient to plot the results of the weekly acid readings graphically, and, following my example, the Edison Companies in New York and Chicago are using now the same method with splendid results. Fig. 8 is the reproduction of the density-curves obtained during 26 weeks on 72 cells, and explains sufficiently the value of this method.

Further, it is essential that not only proper care be given to the individual cells in the battery, but also that the proper relation between the amount of charge and discharge should be maintained. To accomplish this, recording voltmeters are now used extensively, and the curves drawn by these instruments have been found to be

a valuable guide for the operator when using the battery, especially during the charge. In a very short time, there will be on the market a recording hydrometer which will record the drop and rise of the specific gravity in a specially selected pilot cell, and I hope that this instrument will also be a great help for the proper operation of batteries.

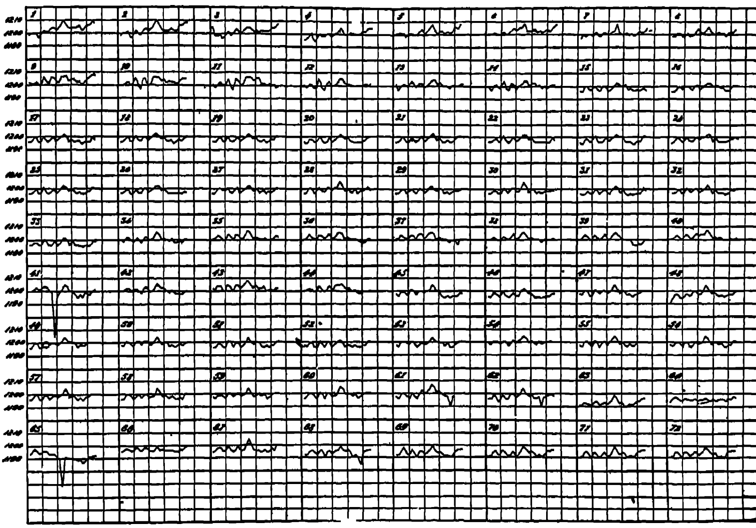


FIG. 8.

As an additional check on the condition of the battery, it is advisable occasionally to make discharge tests, comparing the battery with a pilot cell.

In conclusion I might say that too much care cannot be exercised in giving a battery regular attention, as in any piece of machinery it is the better practice to anticipate trouble, and exercise every care to prevent its occurring, rather than to wait until it develops and then attempt to remedy it.

DISCUSSION.

CHAIRMAN LIEB: It may be desirable to inaugurate the discussion of this paper by calling attention to a few matters that may be of special interest to the representatives from abroad.

This paper is presented as one of the papers from the Association of Edison Illuminating Companies, as a co-operating society. The Association of Edison Illuminating Company has had for a number of years a Committee on Storage Batteries. The Committee on Storage Batteries has

on its membership representatives from the larger electricity supply companies, such as those of New York, Chicago, Boston, etc. This Committee is made up of men who are actually in charge of the batteries of the several companies and they meet at intervals during the year at different points and make comparison of the methods and experiences of the different companies. These comparisons of notes and practice have been found of great value in securing improvements in the manner of handling batteries. I would say that the practice in this country in the handling of batteries is somewhat different from the practice abroad. While in many of the earlier battery equipments they were installed on a maintenance guarantee, in later years this practice has been discontinued and now practically all of the batteries are installed without guarantees. One of the greatest sources of trouble in connection with the handling of batteries has been found to be the depreciation of the floor and the upkeep of the tanks themselves. With the change which has taken place within the last few years in the direction of concentration of the generating equipment, there has taken place also a change in the position which the battery has occupied in the system.

COL. R. E. B. CROMPTON: The paper is an important and useful one, but there is one omission which I am sure you ought to know of. Here in America you appear not to appreciate how much the life and cost of upkeep of a battery depends on the life and cost of upkeep of the regulating cells. The practice in other countries appears to be differentiated. Here you use the old end-cell regulation whereas we are gradually introducing a fixed number of cells and booster regulation. We find in England that although theoretically it seems simple enough to exchange or repair the regulating cells as soon as they have reached the limit of their life, yet that the repair or substitution of new end-cells is a serious matter, interfering greatly with the regularity of the supply. The repair or substitution of a regulating booster is a far easier matter. Reversible boosters of several kinds are now in the market, and form a very welcome addition to the orders of our manufacturing companies. I think I am correct in saying that all our most recent installations of storage have included the booster arrangement.

Another point is that you have told us that the system of maintenance by contract has been practically abandoned by you. On our side the reverse is the case At first we found it impossible to get responsible manufacturers to contract for maintenance on reasonable terms. It was greatly on account of the uncertainty of the manner in which the batteries were used which added to the uncertainty in the cost of the maintenance of the regulating cells, but in view of recent developments and the improvement that has taken place in every adjunct, not only in the cells themselves, but in the containing boxes, the supports and the flooring, manufacturers have now seen their way to undertake maintenance contracts on very reasonable terms.

I must congratulate the various Edison Supply Companies in this country in that they have thoroughly appreciated the great advantages of storage in reducing working costs, and I think that they are following our practice as to the most economical proportions of storage compared

with generating plant to be used so as to deal most economically with the periods of extreme load. I find that the Edison ideas as to these proportions coincide very closely with my own personal ideas, and which I have adopted with considerable commercial success in companies with which I am closely connected.

Mr. ROBERT HAMMOND: We do not want to dwell too long on any one subject, but I would like to take the opportunity of expressing my entire concurrence in the remarks made in reference to the use of boosters. Mr. Crompton is so modest a man that he naturally omitted to say what would perhaps be of interest to the members, and that is that of all the boosters, the one produced by his firm is undoubtedly *the* booster. As one who has been such a zealous worker as he was in the battery field, it is interesting to know that we deem the great success of the batteries on our side of the water very much due to the introduction of the booster. There is also one other point in regard to the maintenance In making contracts for batteries, on behalf of supply undertakings, I always did insist upon this guarantee. It works out at about 7.5 per cent per annum, and for that amount those who guarantee the batteries have to keep them up to their 100 per cent capacity.

CHAIRMAN LIEB· Tanks as well?

Mr. HAMMOND: All through, tanks and plates, the whole thing. Not the floor. The advantage of that is this — there is an inspector always watching these batteries from an outside point of view, and we find that is a very great advantage. When the gentleman in charge of the station is apt to take a step in the wrong direction, he hesitates to do so, because he knows he has an agreement which sets forth the conditions under which he may use the battery, and if he neglects any of the conditions he may ruin the battery. That is a constant remainder to him of his duty. We know how easy it is to step aside from the path of duty — at least in Great Britain — and that is one of those things that keeps us on the right track.

Col. CROMPTON: I find that the mere fact that the whole discharge must go through a reversible booster is a great check on over-discharge to an extent which would damage the main battery of cells. On account of sparking and other reasons it is evident that no one can possibly allow a large over-discharge from a reversible booster.

Mr. M. J. E. TILNEY: I ask whether Mr. Goettling has had any trouble with the thin wooden diaphragms in between the plates — whether there is any special construction or any special wood he uses for these separators, because on the face of it one would think you might possibly short-circuit the cells with the wood. In the ordinary way if you get a piece of wood between the cells you would run your cell down. Another point is — in connection with these very deep boxes. I am connected with a firm that has nearly 10,000 cells in use and 2500 are approximately twenty-five inches in depth Some of the battery-makers objected to supplying deep cells, owing to the enormous difference in the specific gravity of the acid in the top and bottom of the cell, and some of them say that the difference in specific gravity will destroy the bottoms of the plates The longest period during which we have had the big cells in use is two and a half

years; but from experiments which I conducted on one battery, we got a specific gravity of 1.190 at the top, while the specific gravity at the bottom, approximately one and one-half inch below the plate, was as high as 1.280. I should like to know if Mr. Goettling has found any difficulty in regard to this difference in density, and whether it does tend to destroy the bottom of the plate. One other point in regard to what Mr. Hammond said, I think we must be in a particularly happy position, because our maintenance agreements come out, including boxes, plates and everything, for something slightly exceeding 6.5 per cent.

Mr. PETER JUNKERSFELD: In regard to storage batteries, I emphasize what Mr. Lieb has said as to the importance of storage batteries in this country, particularly for large systems. Herein we may also find something to explain our practice of using end-cell switches, whereas the practice in England is to use boosters. We place much dependence on the storage battery and, therefore, like to have the installation as reliable as possible. The addition of a booster would include another element, in this case rotating machinery, and that is the reason we do not use the booster to a very great extent for discharging. Our central station loads are fairly steady and we have not found much difficulty in handling the end-cell switches. Another reason for the use of such a large proportion of batteries is that in December the possible use of these batteries runs anywhere from 15 to 40 per cent of the maximum load. We can often use them to this extent on account of the very sharp peak. Many of the companies can afford to install batteries to carry 15 per cent, 20 per cent or 25 per cent of their peak demand at that particular time of the year, rather than to spend money for equivalent generating equipment.

Mr. GERHARD GOETTLING: The end-cell question is answered by Mr. Junkersfeld. I have nothing to add on that point. I might say that in our Boston practice we have found that we do not need the booster to keep the voltage of the battery more constant, as we understand its use. Our batteries in case of constant changes of the load are never called upon for more than perhaps the one-and-one-half hour rate; they are seldom called upon at the one-hour rate, so that a drop in the voltage at these constant changes in the load does not affect the voltage very much, as we have found by actual readings. The New York Edison, Chicago Edison and Boston Edison Companies are now using the recording voltmeter. The lines shown on the recording voltmeter are very steady, generally not more than half a volt difference in variation in the line.

As to the wooden separators, I will say that we have used the wooden separators since 1901, and they have been in general use since 1902, and during this period we have had splendid results with them. The capacity of the batteries was increased very much as soon as we installed these boards. The boards affect only the negative plates. They have no effect on the positive plates. It might be that the effect on the positive plates is slightly detrimental, so far as it may be the cause of buckling. But these cases are so very rare that they have no effect on the voltage of the battery. The main point is that the installation of the wooden separators increases the capacity of the negative plates. It has generally been the case that the negative plates gave 80 per cent of the guaranteed capacity

before the installation of the boards, and about three weeks after the installation of the boards we got 110 to 115 per cent, so that the life of the negative plate is increased by at least two years. The wood used for the separators is, I think, ash; I do not know certainly. It is a secret of the storage battery company, but the important point is that the battery company sends these wooden boards specially treated, because when you install the dry wood it might give rise to possibly organic acids in connection with sulphuric acid, and cause a too extensive formation of acid on the positive plate and shorten the life. The storage battery company now treats the wood so that there is no danger of any excessive formation of acid on the positive plates.

As to the difference in the specific gravity, I may say I have not found this to be great. Our plates as we are now using them are thirty-one inches long, with thirty-seven inches in height of the acid, but the difference in the specific gravity is perhaps not more than 0.003 or 0.004 on the readings. As to the difference in the acid, the result is not, as some have stated, that the heavier acid at the bottom spoils the plates at the bottom. We find when we take them out that the bottoms of plates are less affected. I have had thousands and thousands of plates taken out, and the buttons on the upper half were eaten out of the plates, and the lower parts of the plates were still intact. It may be that the difference in the specific gravity is compensated for by the difference in current — the specific gravity being lower there is little more resistance in the acid, and so the matter is equalized. I cannot say that we have found any difficulty in using such high tanks. The larger space at the bottom cannot have any effect, because it is a well-known fact that the acid underneath the tank is not changed at all during charge or discharge. The only effect of a difference, or drop, in the specific gravity is between the plates, and not underneath the plates, and it does not make any difference whether you have six or twelve inches at the bottom.

Chairman Lieb: I will consider this discussion closed, and I will now call upon Mr. Percy H. Thomas, who will be kind enough to read the paper by Mr. Henry Noel Potter on "Nernst Lamps." During the reading of this paper I will ask Dr. Jorge Newbery to occupy the chair.

(Dr. Newbery in the chair.)

Mr. Thomas read the paper of Mr. Potter.

NERNST LAMP.

BY HENRY NOEL POTTER.

The Nernst glower is to be a permanent factor in electric lighting, despite its peculiarities, because it does possess optical, electrical and commercial advantages over the carbon filament.

The chief advantage is the possibility of a greater number of candle-hours per dollar. The chief disadvantage is the necessity of setting the glower in operation by devices which add to cost and complication, without having any illuminating function.

In short, the luminous glower beats the incandescent filament at almost every point, but the *cold* glower is a serious handicap.

Commercially speaking, the advantage is continuous, the disadvantage one of first cost. It is obvious that a continuous saving will in time pay off a loss due to increased first cost, and eventually show a profit. Nevertheless, a high first cost, even if paid off in a few hundred burning hours, is a serious handicap to the introduction of a novel lamp, as the prospective consumer fears that the saving will in some way prove illusory. True progress will consider both installation and operation.

With this criterion in mind, it is instructive to note that the development of the glower and the lamp has proceeded simultaneously in Germany 'and America along convergent, rather than parallel lines, toward what is probably the true place of the Nernst system in electric illumination.

Development.

The German development proceeded along the lines of least resistance, letting the evolution of the glower govern the size of the lamp. This involved the study of glowers of various and increasing sizes.

The American development sought rapidly to accomplish prescribed lamp sizes and candle-powers. This involved a concentration on practically a single size of glower, and growth by multiplication.

The German glower was studied on direct current, the American

on alternating, and this resulted in the use of a fused-in terminal not suited to direct current here, and a wrapped and pasted terminal in Europe.

The German lamp adopted the helical or "spiral" heater system wherein the glower is embraced by the heater, and renewed both heater and glower when either failed, but in some of the larger sizes they adopted a modified American overhead system, retaining, however, the compound renewal system, heater and glower together. They finally abandoned the embracing heater in their small lamps in favor of an inversion thereof wherein the glower embraces the heater.

The American lamp has adhered to the independent glower renewal and the overhead heater, having a high first cost and long life, except in small size or "baby" lamps, where, after many trials of long-lived heaters and independent glower renewals, they adopted a cheap heater renewed with the glower.

The greatest difference, however, is in the use of large single glowers abroad, as against a bunch of several small glowers here. The multiple-glower type was the only solution to the prescribed large candle-powers when it was brought out, and even yet the American six-glower lamp has a greater candle-power than has been reached commercially with a single glower. Further, the German company has made lamps with several large glowers in one globe, showing that they do not believe that single glowers for currents of several amperes are an immediate probability.

There can be do doubt that the single large glower makes a cheaper, better lamp than several small glowers of the same total candle-power, because several glowers require a more elaborate heater and heater-supporting structure, a multiplicity of contact pins and connections, several ballasts and their connections and supports, and more labor in assembling, testing and repairs.

More important, however, than the above is the fact that several glowers in one lamp, in practice, break at different times, and the effective life between trims becomes the quotient of the glower life divided by the number of glowers. This is serious, particularly as there is no necessarily fixed time between trims, and convenience in maintenance counts for much, especially in America.

A six-glower lamp in which the glowers average 900 hours life would have to be trimmed about every 150 hours, for the best service. If trimmed every 300 hours, it would run about half the time with only five glowers lighted, and consequently in a con-

dition to occasion and warrant criticism. No one, whatever his attitude toward the lamp, likes to bother to trim it, merely because it is dim. A lamp should be designed with an appreciation of the human nature of the user; few people will bother to attend to anything until it gets so bad they positively can't use it at all. Therefore the best lamp is one which gives good, steady service and requires no attention until it goes out instantly and completely. This, the multi-glower does not do.

Sizes of Unit.

The sizes of unit best adapted to the illumination of large interiors lie from 40 to 150 mean hemispherical candle-power, when cost of wiring and outlets is considered. The 16-cp lamp is too small, as is shown by the extensive use of clusters and the appearance and sale of special, large, round-globe lamps with reflectors. The inclosed arc is too large, as shown by the elaborate reflector systems devised by those who are trying to distribute its light properly over an area commensurate with its cost of operation.

Numerous attempts to make small arcs for two or three amperes prove that even some arc-lamp manufacturers believe that better effects can be secured by lamps of smaller candlepower. As the Nernst lamp is peculiarly suited to what may be termed intermediate candlepowers, every attempt should be focused upon thoroughly covering this field with lamps meeting the criterion of low initial cost, coupled with sustained, economical service.

We may now properly review the Nernst lamp from an engineering standpoint and examine the peculiarities of the glower and of the auxiliary devices occasioned thereby, with a critical appreciation of the problems involved, the solutions offered, and the probability of further advance.

Glower.

The glower may be, broadly, any solid body which is practically a non-conductor of electricity when cold, but becomes a sufficient conductor when heated to permit a flow of current adequate alone to maintain it at a conducting temperature. This breadth of definition is at once narrowed in practice by three considerations:

1. The temperature maintained must produce a commercially efficient light.

2. The life must be long enough to satisfy the consumer accustomed to incandescent lamps.

3. The temperature at which it becomes conducting enough to "start" must be within the reach of a heating device possible to produce, operate and maintain at a reasonable cost.

The first consideration eliminates certain oxides and mixtures which start when heated only to room temperature, but melt below a temperature of efficient incandescence.

The second consideration eliminates any substance or mixture which greatly changes its resistance in operation. The cause of such change may be sublimation, crystallization, polymerization, or the gradual formation of new chemical compounds. These changes are not absent in operative glowers, but they are reduced to a tolerable amount, and to a certain extent balanced against one another to maintain approximate constancy. Certain substances produce rapid or large variation in glower resistance. These must be eliminated, or the last traces of them balanced.

There is still the third consideration of starting temperature noted above. Practical heating devices are dependent upon platinum as the conducting material, and considerations of cost and life limit the temperature at which they can be safely operated. This temperature is not high enough to start certain glower mixtures which otherwise seem to possess excellent qualities.

It seems probable that the experience of the Welsbach mantle will eventually be paralleled in the Nernst glower, and that, gradually more refractory glower mixtures will be used. Such an improvement would increase the efficiency and the whiteness of the light, and might possess other advantages in constancy or life. This is the direction in which greatest progress may be expected, but heater improvement must lead the way.

It is not at present possible to make the same glower operate interchangeably on alternating and direct current, or to reverse the established polarity of a direct-current glower. The difference in action between the two currents is so great that two distinct types of terminal have been developed. The best terminal for alternating service consists of a platinum bead fused into one side of a larger bead of glower material at each end of the glower. The advantages of this terminal seem to be purely mechanical, in that a large area of platinum and glower are firmly pressed together and protected from displacement in transport and use.

A direct-current terminal must be ventilated, so to speak. The theory of Nernst[1] that the glower is an electrolytic cell wherein

1. W. Nernst, *Zeit. für Elektrochemie*, 6, p. 41, 1899.

oxygen is the negative ion and either atmospheric oxygen or oxygen dissolved and diffusing within the glower is the depolarizer, has received in the investigation of Bose[2] such experimental support as to leave no reasonable doubt that such is the case. Oxygen must therefore reach and react with the reduced metal at one electrode and anodic oxygen liberated must escape.

The sealed-in terminal hinders or prevents this oxygen flow and is therefore restricted to use where electrolysis is so short lived and so completely reversed as to be practically absent. This is true with alternating currents delivering equal coulombs positive and negative. The observation of Wurts[3] that alternating-current glowers have longer life on higher frequency, doubtless finds its explanation in an extension of the above reasoning.

The direct-current terminal consists of strands of fine platinum wire looped about the end of the glower and twisted to give contact. The interstices between wire and glower are filled with ground glower material forming a porous lump. This terminal is easy to make, but hard to standardize, as it is largely hand work.

A glower should start at a dull red heat and its resistance decrease at a rate increasing with the temperature and current until the resistance decreases as fast as the current increases, so that their product, or the voltage across the glower, reaches a maximum. Further current increase is accompanied by decrease of voltage.

The voltage maximum is called the "knee" of the voltage-current characteristic, and in practice the glower is operated at or near the "knee," as above this point the life is inadequate and the regulation naturally increasingly difficult, since the glower is in a state of complete instability as to electrical relations.

Two observations are of practical importance in this connection: First, that in glowers of different thicknesses, the "knee" occurs at different surface temperatures; and second, that the same glower will have different resistance characteristics in different gases.

It is obvious that closely surrounding an operating glower, and within its pores, we have all the conditions necessary for the ionization of a gas, together with a potential gradient of sufficient steepness—about 70 volts per centimeter in 0.4-ampere glowers—to maintain appreciable electric current in the gas in and about

2. E. Bose, *Ann. d. Physik*, 9, p. 164, 1902.
3. A. J. Wurts, *Trans.* A. I. E. E., XVIII, August, 1901.

the glower. The strength of such currents and the temperatures at which they will become appreciable will differ in various gases, and this may well explain the peculiarities introduced into the glower characteristic by the atmosphere in which it runs.

The leakage current through the gas gives no great amount of light, but doubtless helps to destroy the glower structure and makes a bad resistance characteristic still worse. It may be that gas conductivity will set a limit to improvement. There is some evidence that a glower will operate on direct current to advantage in an atmosphere of oxygen, but this would involve a sealed globe.

The efficiency is less, the thicker the glower, because the resistance decreases faster along the axis of the glower than at the relatively cool surface. The current thus concentrates near the axis and in thick glowers may even melt the inside before the surface is hot enough to be an efficient light source. The most obvious remedy is to remove the axial portion and make a tubular glower. Such a tube may operate well, provided the glower mixture be very even and the tube wall equally thick everywhere and free from physical deformities of all kinds, and provided the "knee" temperature is not greatly exceeded—otherwise the current develops a path of least resistance along one side, or sometimes along a crooked line or spiral from terminal to terminal and there fuses and destroys the glower.

By great care in the selection of earths, in making the mixture and in forming and mounting the glower, it is possible to manufacture glowers for about 1.2 amperes. In the laboratory, larger glowers have been successfully operated.

Light Efficiency.

The comparison of the useful light radiated by the alternating Nernst lamp and its competitors may be made on a basis of the mean candle-power throughout the whole sphere, or any portion or zone agreed upon. Mean spherical candle-power is not a utilitarian basis. The mean lower hemispherical is more nearly practical, except that light radiated but slightly below the horizontal, strikes floor surfaces at such distances and at such angles as to be of little illuminating value. In a large area lighted by many lamps, the nearly horizontal beams from any lamp fall within the brightly lighted fields of other lamps where they are not needed. They are also the beams which produce most of the objectionable, dazzling effect.

For these reasons, it is thought that a fair comparison of relatively useful illumination can best be made on the basis of the mean candle-power throughout a lower polar zone 75 deg. in width, measured from the vertical. In the following table, a comparison is made between a Nernst lamp, a cluster and a reflector lamp. The cluster consists of five 3.5-watt carbon-filament lamps, each giving 16 mean horizontal candle-power, mounted beneath a 14-in. opal-glass reflector. The Nernst lamp selected for comparison is an American type, 264-watt lamp, equipped with an opal heater case and a dome shade. The reflector lamp is one of the 5-in. spherical, frosted globe type. The corresponding figures are also given for the 528-watt Nernst lamp, with opal heater and dome shade. This, however, is not an intermediate size, being more nearly comparable to an inclosed arc, than to any ordinary cluster of incandescent lamps. The mean horizontal candle-power is also given:

	Mean 75° polar zonal C. P.	Watts per mean Z C. P.	Mean hemispherical C. P.	Watts.	Mean zonal candles per kilowatt.	
3-glower Nernst lamp, initial	160	1.64	127	264	....	Initial.
5-lamp cluster, initial	95	2.93	86	280	....	
Reflector lamp, 5″ globe, initial	40.5	2.92	86	118	....	
3-glower Nernst lamp, average 800 hours	119	2.22	....	....	450	Average.
5-lamp cluster, average 800 hours, approximate	87.5	3.2	....	....	313	
Reflector lamp, average 800 hours, approximate	29	4.1	....	....	244	
3-glower Nernst lamp, after 800 hours	105	2.5	....	....	....	Final.
5-lamp cluster, after 800 hours	79	3.5	....	....	....	
Reflector lamp, after 800 hours	26.5	4.5	....	....	....	

It will be understood that no exact comparison is possible as the distribution at different angles is not strictly proportional in the various types selected. The figures given are intended to illustrate approximately the best results which can be expected under practical conditions.

It is thus seen that the Nernst lamp at the end of its run is better than its competitors at the beginning of theirs, and that 70 cents' worth of current will give the same service in a Nernst lamp as a dollar's worth in a cluster, with the reflector lamp a

bad third. It should be explained that in the cluster, 3.5-watt lamps are chosen rather than 3.1-watt lamps, as the latter are not long lived enough for a fair comparison with the other types. The Nernst lamp efficiency could be considerably raised and still have the effective life of the 3.1-watt carbon incandescent.

Auxiliary Parts.

There are, unfortunately, other parts in a Nernst lamp beside glowers, and much depends upon their reliability. The steadying resistance or "ballast" is one of these. The characteristic of the glower, as described above, is not adapted to operation upon constant-potential service without a steadying resistance in series with the glower. To illustrate, assume that the glower is operating at the "knee" of its characteristic, where slight increase of current is not accompanied by any change in voltage, and that in series with the glower is a steadying resistance of "constantan" or other alloy having almost no temperature coefficient. The resistance of this ballast may be assumed equal to that of operating glower, so that half of the wattage is in the glower and half in the ballast. The current will increase twice as fast as the voltage, which in itself is an intolerable condition, aside from the fact that half the watts are in the ballast, and the efficiency of the lamp but half that of the glower, and hopelessly out of the race.

Inductance in the place of resistance is possible in alternating lamps, but while this might save power, it would give a lamp with current displaced in phase, and high lamp voltage relative to glower voltage.

A remaining possibility was to substitute for the "constantan" a resistance which increases as the current increases, the more the better. The resistance increase, however, must take place very quickly after the current increase, or the latter will momentarily reach such strength as to destroy the glower, which has little heat capacity. Very fine iron wire possesses the required properties in such a high degree that trebling the voltage across a length of it may increase the current only 10 per cent. The change in resistance also follows the change in current very rapidly in the wire itself. To secure this enormous effect, however, it is necessary to have the normal glower current heat the wire to a particular point, namely, almost to the temperature of recalescence, so that an increase of current will cause the iron to pass through

this critical region within which sudden resistance increase occurs, due probably to molecular rearrangement.

It is convenient to have the ballast resistance short in length, and it is thus desirable that it should be of the smallest diameter possible for its normal current The normal current and the normal temperature being both fixed, the only way to control the diameter, and thus the length of wire, is to vary the heat-dissipating power of the gas surrounding it. Of course, the wire would burn up in air. and so some inert gas must surround it, but it is not a matter of indifference which gas is used, the thinnest, shortest wire for given conditions being possible only in hydrogen, which has the greatest heat-dissipating power of all the gases.

The use of a hydrogen atmosphere involves a container and this introduces difficulties, because this container, made of glass, heats up slowly and causes the ballast wire to creep up in temperature and resistance, thus affecting the current in the glower. Further, when the container is of lead glass, the hydrogen reduces the lead oxide in the glass, throwing out black metallic lead and introducing moisture into the ballast atmosphere. Fortunately, this only occurs when ballasts are run abnormally hot; so, instead of using glass free from lead, the latter is retained and the blackening of the ballast used as a certain indication of excessive over-voltage.

When a ballast is cold and its glower is started, the ballast must be brought to normal operating temperature before it can steady the glower. The heat capacity of the ballast is such that it takes an appreciable interval to warm it up, and consequently the glower gets a momentary excess current, which is injurious, but not so much so as to seem to warrant further complications in the lamp to avoid it. It has been found that all creeping is eliminated by operating the ballast under water, which, while hardly a possibility in a lamp, is convenient on a photometer. In the large German lamps, the ballast container is surrounded by a close-fitting jacket of metal plates which act as a cooler. In multiple-glower lamps there are multiple ballasts, and such jackets would be too complicated and are sacrificed.

HEATERS.

The next feature of interest is the heater system. Lamps were at first made with movable, cup-shaped heaters, drawn away from the glower magnetically so as to permit unimpeded radiation of light. These heaters were very powerful and lighted the glower

very quickly, but they were clumsy and likely to get out of order, so the stationary heater was developed. The tubular heater was the earliest practical form brought out. It was first placed under the glowers and some very pretty lamps modelled after gas lamps were made.

Finally the tube heater was dropped in Germany and inverted in America, so as to be above the glowers. This is the slowest starting position, but the best optically, and cannot be injured by sagging glowers. The spiral or helical heater, made by winding a long, thin kaolin rod with platinum wire and then heating and bending the rod into a helix, proved to have many advantages, as it is cheap, starts the glower quickly and heats it in any position almost equally well. It obstructs less light than is generally supposed. It is the only practical heater for starting vertical glowers. Heaters were first made with bare platinum, but this causes rapid blackening of all adjacent surfaces. Enameled surface heaters were then tried, but these proved short-lived. At present the wire is coated with a porous covering which minimizes both defects noted.

An interesting inversion in the study of the heater was the necessity of finding a supporting material that would not conduct when heated. The first heater supporting tubes, etc., when operating became so conducting as to sparkle with tiny discharges between wire and support, and to quickly destroy the former. Substances and mixtures are now known which are practically non-conducting at the highest temperatures the heaters ever attain.

Cut-out.

The last auxiliary device to be considered is the cut-out which interrupts the circuit through the heater when its function has been performed. There have been more different cut-outs devised and tried than anyone would believe from an *a priori* consideration of the problem. There are, broadly, two classes, thermostatic and magnetic. The former system is very attractive, especially when operated by the ballast heat, and may yet be made reliable and sensitive enough, but all lamps now on the market have magnetic cut-outs. The American cut-outs are all made without springs, the movable contact-making member being held in contact by gravity and out of contact magnetically by a coil in series with the glowers. The German lamps use a spring-closed cut-out, which

doubtless works well on direct current, but which has never proved reliable on alternating current, in American experience.

The great difficulty in cut-out design is to devise one which shall not deteriorate at the high temperature to which all parts are heated, which shall not hum on alternating current of any usual frequency, and which can be made in quantities without individual adjustment. The nearest approach to a solution as yet is to have the moving member act as a pendulum, both gravity and the magnetic pull being downward, the latter making only a small angle with the vertical. In this construction the weight of the moving member is never lifted from the support.

The gravity cut-out necessitates operating the lamp in a predetermined position, and as yet the pendant position is the only one provided for. The spring cut-out is advantageous in small lamps for use in ordinary fixtures, because these must be of the "Universal" type, capable of operation in any position.

A second kind of cut-out is used in lamps which are not readily accessible; its function is to interrupt the heater current when the glower refuses to light, due to breakage. It is a plug and socket forming part of the heater circuit. Within the socket is placed an explosive charge. The heater current in these lamps exceeds the glower current and heats the lamp in about five minutes to the firing temperature of the explosive. This blows out the plug and cuts out the heater.

The commercial development of the Nernst lamp has not yet reached certain lamp arrangements and systems of operation for which the glower is suited. For example, the ballast and cut-out may be removed from the lamp structure and located at a distance. This leaves only the glower and heater in the lamp, but involves three terminals and a new type of base and socket. The advantages of this system are a smaller lamp, which will burn in any position without recourse to spring restrained cut-outs, and the freeing of the ballast from restrictions as to size and the necessity for operating within a heated lamp housing.

There are the undeveloped possibilities of the constant-current system, which is particularly attractive as the ballast with its loss of efficiency falls away, and the life characteristic of the glower can be more easily controlled. In fact, it is possible to make a constant-current glower, which increases in candle-power and efficiency as it gets older, though naturally at the expense of long life. This is probably an advantage.

Akin to the constant-current system is the series constant-potential system, with or without shunt boxes.

It is evident, therefore, that the Nernst system has hardly approached its limits in any direction, and that it still presents a field full of fascinating problems for the chemist, physicist and engineer, while in its present development it has reached a stage where it should present no problem to the station manager and the light consumer.

Discussion.

Dr. Jorge Newbery: I would say that in Buenos Ayres the Nernst lamp is very extensively used. You cannot pass through a street but you will see some Nernst lamps, both direct current and alternating current. They are made in Germany. I may add that the German company has entered into competition with the gas company for public lighting by Nernst lamps.

Mr. Robert Hammond: What we found is this — that the number of hours of use is not uniform. That has been our greatest difficulty up to the present time. Of course, for public lighting the one necessity is that at a given time your man in charge should go down the street and renew or not renew. We made a practical proof of a number of lamps for lighting a number of streets in a particular district of London, and we made the most careful observations as to the lives of the lamps. We had one lamp which died in fifteen hours, but his brother, the next lamp, lasted for 600 hours. We renewed the fifteen-hour lamp and put in his son, and the son lasted forty-five hours; but the lamp on the other side of it went on for 350 hours. Finally, the result of six months of this work was that we went back to arc-lamps. We feel, as far as the results of those which went to the age of Methusaleh, that these young ones which went out at the critical moment spoiled the whole thing. I am sure it would be very pleasant for us to hear the experience in the use of these lamps for private lighting, because the private lighting presents a different problem — you can have a lamp go out and renew it in the house at any time; but for public lighting, you cannot afford to have your lamps go out at the wrong time. I am sure we would be glad to get the experience of our American friends as to the reliability of the Nernst lamp in its present state of development for public lighting.

Mr. George Wilkinson: I have not had a very large experience with the Nernst lamp, but it may be of interest for the gentlemen present to know that recently I was able to fix up an arrangement with the German company for the supply of Nernst lamps in which they undertook to renew free of charge any filaments or heaters which failed with a less average life than 450 hours. The guaranteed life has since been increased from 450 to 600 hours. My early experience with the lamps was as disastrous as Mr. Hammond's, and I have had as many as three burners give out in twenty-four hours. Under this agreement with the German company I am arranging to light three streets experimentally with the Nernst lamps, and in order to avoid entire extinction of the light, due to the

failure of the heater or glower, I am arranging to put two lamps side by side in each street lantern. This forms a satisfactory arrangement, and it does not entail any alteration of the existing gas standards or lanterns, and the electric fitting which is put in is simple and cheap. I am hoping that the results of this investigation, which we are going to carry out carefully, will demonstrate that we have a method of street lighting with Nernst lamps which will compare with our great competitor, the Welsbach gas mantle.

Mr. A. G. T. Webb: The speakers have referred particularly to the Nernst lamp as used for street lighting, but it occurs to me that the Nernst lamp is particularly adapted for interior illumination. The one feature to which attention will have to be given, in order to better adapt it for interior illumination, is the question of the rapidity of lighting. The trouble which we have found, the objection which has been stated, very largely, against the Nernst lamp, where used for interior lighting, is the length of time it takes to bring the light to full incandescence. This is more particularly the case with the type of lamp with the horizontal web, the glower placed above it. I think that is an objection to the use of the Nernst lamp for the interior lighting of stores and buildings, owing to the fact that the light may be required at very short notice, and under these conditions the Nernst lamp is practically useless. The length of time that it takes the lamp to come to its full brilliancy, especially with the horizontal glower type, appears to be quite important to the user. I have made a record of the time it takes for the lamps to get up to full incandescence, and it takes as much as one minute to a minute and a half. That seems to make it quite prohibitive for interior lighting, whereas its actual illuminating qualities are very desirable for such uses.

Chairman Lieb: In speaking of the Nernst lamps, it is of interest to know whether Mr. Hammond, in the experiences which he gave us, referred to the alternating-current or the direct-current lamp.

Mr. Hammond: I referred to the direct-current lamp.

Chairman Lieb: There are practically no American lamps used to any extent on direct-current distribution. The Nernst lamps in America are confined practically to the alternating-current work. In that respect American practice and experience differ from English practice and experience.

Mr. Wilkinson: The observations I have made referred to alternating-current supply at fifty periods per second and 200 volts. There is another town with which I am connected, in which Nernst lamps are used solely for street lighting. There is only one in each lantern, and we have obtained very excellent results. I think it is largely due to the fact that the lamps are running on battery current. The batteries are charged by water power, and at night the whole of the lighting is carried by the batteries; under these conditions we find the Nernst lamps are giving satisfactory results, and that the life of a lamp averages about 800 hours.

Mr. Lewis A. Terven: You called for remarks rather from people who use the lamp than the manufacturers, and I happen to be connected with the Nernst lamp, as the head of the engineering department of the American Company. One gentleman brought out the erratic character of the

life of the glower. I find that in the literature on this subject, in Germany and in America, the first thing mentioned is the inconsistency of the glower, that is to say, it may last fifteen hours, or it may last 1200 hours. If the glower has not ample room for expansion on starting. it will not begin favorably; but if it survives the first 100 hours, it is good for a life of 1200 hours or more. It is important to start the lamps properly, and I think a large number of failures are due to the fact that the people who handle the Nernst lamp do not understand its peculiarities, do not know how to allow for expansion and still get the proper tension on the glower. The Nernst lamp is a difficult proposition, but when handled right, like the induction motor — which we all agree to be superior to the direct-current motor, although more complicated in design — it is satisfactory. It is the same with the Nernst lamp — although it is extremely complicated, we know it will operate well, and when you know how to operate it properly, it gives far better results than the ordinary carbon lamp. I feel sure that the more we know of the Nernst lamp the more it will be used. As to the street-lighting proposition, I know that street lighting with Nernst lamps has been declared to be a failure by many, but it has been declared to be a success by a far greater number of those using the system. The single-glower lamps for street lighting have come into use, and they are quite as good as the multiple-glower systems. Many people have used these single glower lamps to duplicate arcs, placing them on street corners. As for the life of the glowers, I know that at Sewickley, just outside of Pittsburgh, they got 1200 hours average life, and had the nerve to complain when the life fell down to 800 hours. On twenty-five cycles the glower is not so good as on sixty or 133 cycles, for the glower is liable to break at the terminal bead. As to the time of lighting, it is usually given as thirty seconds. It rarely goes over a minute. For store lighting the lamps are largely used in the evening. A man turns on the switch when it begins to get dusk, and in my opinion the time of lighting is not important, because quite a number of people used to depend on series arcs in front of their establishments, and they had to start their lamps when the station got ready to put the current on. We are perfectly willing to design a lamp that when you turn a switch, you will secure light immediately; but the consensus of opinion, so far as we have been able to obtain it, is that the people do not care whether they get light in one minute or in two minutes. This is a matter we have taken up several times, and we base our designs on the opinions of the people who expressed themselves as not caring whether the lamp lighted quickly or not.

In conclusion I will turn to one subject not mentioned in Mr. Potter's paper, and that is the quality of selective radiation of heated bodies. The carbon filament has a black surface and I understand that a black surface is the same whether it be hot or cold. At any rate, such a body radiates mostly in the invisible spectrum. The Nernst glower is supposed to be a simple luminant without selective radiating capacity, or the radiation emitted at any temperature of the glower is equal and similar to that emitted by an equivalent black body at the same temperature. Now, there are quite a number of substances which display a marked selective

radiation, tending to dissipate the energy in the visible spectrum. A glower made from such substances might give a candle power at 1700 degrees C, equal to that given by the regular glower operating at 2100 degrees C. I think that this suggests one field to enter — to increase the efficiency without increasing the temperature at which the glower is operated. If we run at a higher temperature with our present glower while we increase the efficiency, we get into certain glower troubles and also parch up any heating devices near the glower.

Mr. Arthur Williams: I think it is unfortunate that the Nernst lamp in this country has not been built for direct-current service. I do not think with the lamps we have had — with few exceptions of the alternating-current type — we here know what they really can do. Unquestionably, instantaneous incandescence is an advantage for interior illumination. It is not so important for exterior lighting, but the desire to throw on a switch and produce light instantly is a feature which is very much talked of, and that is a feature which we have in the incandescent service, and it is a disadvantage in the commercial exterior use of the Nernst lamp. In New York, in our suburban territory we have 300 or 400 Nernst lamps on alternating-current, and we find the average life is approximately 400 hours per glower, and that the Nernst lamp has become a very potent means of competition with Kitson and other intense gas burners. The small single glower lamp has not fulfilled our expectations, but the three and six glower lamps have given entire satisfaction. That kind of lighting, cheap gas lighting, is usually of long average use, and where it can be replaced with the electric lamp, you will find a very high average return. That statement is borne out in our experience with the Nernst lamp, the extension in the use of which has been largely confined to competition with cheap gas illuminants or oil. The average return per 50-watts standard is practically double the average return for the same standard in incandescent or arc lighting.

Chairman Lieb: The time is rather short, and I am afraid we will have to curtail this interesting discussion. I will therefore close the discussion and we will proceed with the consideration of the steam turbine, on which we have three papers.

The name of Mr. W. L. Emmet is so well known to you all as the engineer of the General Electric Company, who has had upon his shoulders the important responsibility of the commercial application and development of the Curtis steam turbine, that no intoduction of Mr. Emmet is necessary. Mr. Emmet has the floor.

Mr. Emmet then read his paper on steam turbines.

EFFECT OF THE STEAM TURBINE ON CENTRAL STATION PRACTICE.

BY W. L. R. EMMET.

Since there are few completed steam-turbine stations which can be considered thoroughly representative, and since the turbine art is new and still in a state of rapid development, it will be best in discussing the subject here selected to deal with the possibilities of the future, rather than with results actually accomplished. Decisions concerning the relative advantages and disadvantages of turbines as compared with reciprocating engines, and concerning the methods by which the best results can be obtained from steam turbines, are of very vital importance to all engineers at present engaged in new or prospective developments. When the plans of a station are adopted the owner necessarily commits himself to many large expenditures, and all of these expenditures should be made to conform to a system of operation which is to be followed for a considerable period of time. If central stations are designed without such definite plan they are almost certain to involve a waste of money and to lead in a short time to new developments and reorganizations. There is probably no department of industry in which foresight is more valuable than in this matter of central station design.

Since steam turbines differ from other steam engines in many important respects, it becomes necessary to make special provisions for their use if their greatest advantages are to be made available. It consequently becomes very important for designers of power plants to decide in advance whether steam engines or steam turbines are to be used, and in deciding this question the immediate prospects of development in steam-turbine design should be considered as well as the results which have up to the present time been actually achieved.

All reciprocating steam engines operate upon the same principle, namely, the pressure of expanding steam upon pistons. The degrees of economy in steam engines depend upon the perfection

of the methods by which this application is made. Improvements of economy in steam-engine designing are effected by various perfections of arrangements and multiplications of parts and are limited by considerations of mechanical expediency of speed and of cost. By multiplication of cylinders high degrees of expansion are obtained without undue increase in cylinder condensation, and by special arrangement of valves clearances are reduced to a minimum, and a distribution of steam effort is arranged in the most advantageous manner. The greatest restriction of possible economy in the reciprocating engine lies in the limited range of its expansion. As steam expands to low pressures its volume naturally increases in a rapidly multiplying ratio, and this increase of volume is so great that it soon passes the limit of capacity for which cylinders can be profitably designed. There is thus a large proportion of the available energy due to expansion of the steam which cannot be used in reciprocating engines, and which must be lost in the form of heat in exhaust steam.

I have recently examined some tests of a very modern and highly efficient generating plant with large compound engines, and these tests show that only 1 per cent of improvement was obtainable by increases of vacuum beyond 25 ins. With steam coming from boilers at 150 lbs. gauge pressure, the available energy per pound expanding to a 25-in. vacuum is 213,000 foot-lbs. The available energy in expanding to a 29-in. vacuum is 272,000 foot-lbs., so that in this case there is 27 per cent of the expansive force in the steam untouched by the engine under its most favorable conditions of operation. This amount of waste effective force is, however, not all that should be considered, since the engine begins to be an inefficient abstractor of energy at a much higher pressure than that of a 25-in. vacuum. The best engines open the exhaust at a pressure of 7 or 8 lbs. absolute, and consequently lose a large proportion of the expensive force of steam below that point, the degree of vacuum below the point of exhaust only serving to diminish the back pressure and not implying an effective expansion to the vacuum point.

The steam turbine possesses the inherent advantage that it can be so designed as to work effectively to very high degrees of expansion in the steam. Since the steam in the turbine is not confined to chambers where it must exert pressure, it is available for doing work as long as it possesses expansive force capable of imparting an effective velocity to the steam itself. Steam turbines can thus

be designed to work to the highest degrees of vacuum, and the efficiency of action at the extreme limits of expansion can be made as great as that in the initial processes where pressure is high. Thus the steam turbine operates in a larger field of theoretical possibility than does the steam engine, and if in all its processes it can be made equal to the steam engine in efficiency of action, it will give from 30 to 40 per cent more useful work from a pound of steam.

Because this theoretical possibility exists, it must not be assumed that such a result is easily obtainable, and it is probable that many years will elapse before any large proportion of this theoretical possibility is realized. The best result in steam economy which has yet been obtained by a steam turbine in practical operation has been almost exactly equaled by highly improved modern reciprocating engines of the same size operating under similar conditions. It may, therefore, be said, speaking generally, that the steam turbine has up to the present time simply overtaken the steam engine in the matter of steam economy, and that its other advantageous features constitute the most obvious reasons for its adoption. While in most cases these other advantages amply justify the installation of steam turbines rather than reciprocating engines, they should not alone be considered; due weight should be given to the great prospective value of the steam turbine idea, and builders of central stations should not commit themselves to conditions unfavorable to steam turbines in the face of the rapid advances of the turbine art and the certainty of continually improving results.

While steam turbines have been built and experimented with for a period of 20 years, their development on a large scale for central station use has been confined to the past four years, and the advances made within the past two years have first brought the steam turbine to the serious consideration of the whole engineering world. The work which has so far been done upon steam turbines has been much restricted by manufacturing considerations and by the absence of the most essential experimental data. The process of experimenting with steam turbines is peculiarly difficult and their action is such that nothing but experimenting can bring about an ideal system of design.

Many engineers may consider that the part of conservative wisdom is to adopt only apparatus, the usefulness and the reliability of which has been well established by experience. There are many

cases, however, in which such reasoning cannot be wisely adopted. and among these the case of steam turbines is conspicuous.

Apart from its possible efficiency, the principal advantages of the steam turbine are simplicity, moderate cost, low cost of maintenance, economy of space, economy in foundations, absence of oil in condensed water, minimum labor and skill required in attendance, possibility of installation on any kind of ground or on the upper floors of buildings, perfect speed control, absence of pulsations in speed, absence of expense for lubricants, diminished danger through possible destructive speeds, and large overload capacity.

The degree of these advantages is naturally hard to judge in the present state of the turbine development, and is undoubtedly very different in different turbines now operating. The most improved turbines which have been produced attain all of these advantages in such a degree as to give heavy weight to the balance of judgment as to whether reciprocating engines shall or shall not be used in new installations. In the cases of certain large central stations which have come to my notice, the adoption of turbines has effected a saving of about 5 per cent in the cost of buildings alone through the adoption of turbines instead of reciprocating engines whose steam economy was assumed to be the same. This saving does not include the saving in foundations necessary to support the engines themselves, and does not consider the economies accomplished through the fact that a station for steam turbines can be put on almost any kind of land without unreasonable expense for foundations. Any surface which will satisfactorily support a battery of boilers can at trifling expense be made to carry the steam turbine which they will supply, whereas in the case of reciprocating engines heavy expenses for foundations are in many cases necessary.

Another of the advantages mentioned which is of great practical importance is the absence of oil in condensed water. The condensed steam from almost all of the turbines which have been installed by the General Electric Company is being returned directly to boilers, and this reuse of condensed steam in many cases effects a large saving either in bills for feed water, or in the expense of maintenance and cleaning of boilers. In this connection it may be desirable to consider the possible corrosion of boilers through use of such condensed water. The ideas which prevail upon this subject seem to be various and inconsistent. It

is generally considered by practical steam men that condensed water causes rusting of boilers, and there is no doubt that under certain conditions it does so. The fact seems to be that pure distilled water with air in solution attacks iron very rapidly, and that a small percentage of impurities of certain kinds will neutralize the free oxygen in solution and prevent corrosion. In naval vessels, where distilled water is constantly used in boilers, injurious corrosion is prevented or limited by the use of a certain amount of fresh water obtained from shore, which I am told accomplishes the desired purpose. Rusting of boilers must come from free oxygen in solution, and it is certain that this oxygen can easily be neutralized and that all trouble from its presence can be avoided. It is also probable that there will be no appreciable rusting of boilers where the conditions are such as to prevent the introduction of air with feed water. Where dry air pumps with high vacuum are used with surface condensers it is probable that the feed water will enter boilers almost entirely free from oxygen in solution, and that no rusting will be observed. While I have heard many expressions of fear concerning trouble from this cause, I have not as yet heard of any such trouble in connection with a turbine installation.

When a consideration of the above-mentioned conditions has lead to the adoption of turbines in any installation, the plant should be so designed as to accomplish the greatest advantages from their use, and the matter of first importance is to procure a good vacuum. In steam turbines of the most improved design impairment of vacuum through leakage of air can be almost entirely prevented. The packings, where shaft passes through shell of turbine, can be sealed with steam in such a manner that leakage of air is impossible, and all the joints below the atmospheric pressure can easily be made perfectly tight, since their temperature is not excessive, and since the simple application of heavy paint to the exterior will generally accomplish the purpose even where joints are not perfectly made. In reciprocating engines the value of high vacuum is not very great, and, consequently, great efforts have not been made to attain it. Considerable leakages of air occur at various points about engines and exhaust connections, and the designs of pumps and condensers used have in many cases not been adapted to the production of high vacuum. Thus, engineers experienced in steam-engine work have become accustomed to degrees of vacuum which are too low for the best

results with turbines, and such men generally consider that the production of a vacuum of 26 ins. or 27 ins. shows a good normal operating condition.

In the introduction of turbines the advantages of high vacuum have been considered, and special efforts have been made in that direction. As a result of these efforts very high degrees of vacuum are being continually maintained at present in many turbine installations. In one installation, where sea water is used for cooling, a vacuum within one-half pound of zero pressure is obtained. In another case a vacuum within 1 lb. of zero is being obtained with circulating water constantly above 80°. In another case a corrected vacuum of 28 ins. is being almost constantly maintained with a cooling tower and wet air pump. In the Chicago Edison Company's installation a vacuum within 0.6 lbs. of zero pressure is being maintained with circulating water from the Chicago river. These, and many other cases, show that high degrees of vacuum are commercially attainable with turbines, and the advantages of such vacuum should be duly considered when installations are designed.

The trouble sometimes experienced in getting good vacuum with reciprocating engines leads many engineers to magnify the difficulty of this matter. Experience has proved that under common conditions high vacuum need not involve any great expense. In a certain installation now operating a turbine tested a few days ago delivered 1000 horse-power exhausting into a surface condenser with 2700 sq. ft. of cooling surface; the temperature of circulating water was 78 and its volume was 50 times that of the condensed steam; the vacuum was 27.8 ins., the temperature of condensed water being only 7 deg. below the theoretical temperature corresponding to the vacuum pressure. While in this and other cases good vacuum is obtained with condensers of moderate size, and a moderate supply of circulating water, it will generally be economical to use larger condensers with a very ample supply of circulating water, and very perfect air-pumping facilities.

In steam-engine installations the advantages of condensation are often considered insufficient to warrant the installation of cooling towers where condensing water is not available. The much greater value of vacuum in turbines will, however, make it worth while to install cooling towers in almost all such cases, even where exhaust steam may be used for heating during a large part of the year.

Another matter of importance in the design of turbine stations is that of superheat. The most improved and best turbines show large improvements of economy with superheating, and while the cost of producing superheat is a matter much in dispute, it is generally considered that superheat is advantageous from an economic standpoint. The most improved turbines are adapted to use with high degrees of superheat, and the use of superheat with turbines is not accompanied by the difficulties or inconveniences which may be occasioned in reciprocating engines.

Since, as has been stated, the best steam turbines so far developed give degrees of economy about equal to those of the best steam engines, and since the turbine, as explained, works in a larger field of available energy, it may naturally be inferred that the steam engine within its own range of action is more efficient than the steam turbine, and this to a certain extent is true. This fact naturally suggests a combination which undoubtedly has a large field of application, namely, the use of low-pressure steam turbines taking exhaust steam from existing reciprocating engines. It is probable that such combinations will only be a phase of the steam-turbine development, since it is highly probable that efficiencies as high as the best steam-engine efficiencies will soon be attained by turbines under all ranges of pressure and that it will become desirable for many economic reasons to discard reciprocating engines altogether.

The most advantageous conditions for the combined use of reciprocating engines and steam turbines will be found in existing steam plants where reciprocating engines are used to operate electric generators separately or in parallel. In such plants low-pressure steam turbines can be installed and can be arranged to take steam directly from the exhaust pipe of engines without valves or governing mechanisms. The turbines would be designed to give a very high efficiency with highly expanded steam and a condensing plant should be installed adapted to the highest degrees of vacuum. The low-pressure valve stems and rod packings of the engines should be sealed with steam and other provisions should be made for the exclusion of air. The steam turbine should operate a generator adapted to connection in parallel with that driven by the engine. A turbine designed for operation under these conditions would be an ideally simple affair and its maintenance and care would add little or nothing to the cost of station operation. There

are many large stations in which the introduction of such turbines with proper condensing facilities would increase the output as much as 30 per cent without any increase of the fuel consumption or change in the boiler plant. There are probably very few stations operated with reciprocating engines where the introduction in this manner of properly designed turbines would not increase the output as much as 20 per cent. In one case recently considered 15 per cent could be added to the output of the station without diminishing at all the work now being done by the engines; that is, such an amount of work could be obtained with degrees of vacuum pressure entirely below those from which the engines are capable of deriving any benefit. In such cases it would generally be desirable to so design the turbine that under full-load conditions it would take steam at a pressure of about 8 lbs. absolute, corresponding approximately to the exhaust point in the low-pressure cylinder of engine. The engine would then handle all the power which it could handle with maximum efficiency, and its own output would be only slightly reduced. The turbine would handle the power to which the engine was not well adapted. Under conditions of light load some economy might be effected by changing the cut-off conditions in the engine, but it would probably be better to leave all the conditions fixed and to allow the pressure on turbine to vary as the load changed.

Such low-pressure turbines would occupy a small space, and there are probably few existing engine plants in which room could not be provided for their installation. The cost of installing such turbines with complete condensing facilities should not exceed $60 per kilowatt of capacity added to the station. This in itself is a small expenditure for an additional plant, even if we do not consider the fact that the use of this additional plant does not call for any increase in fuel consumption or in steam-generating apparatus.

The following table shows the approximate increase of output which can be obtained by using a low-pressure turbine with good vacuum worked in series with a good Corliss engine, over that which could be obtained from the engine alone when used with the best vacuum. The engine considered would consume with atmospheric exhaust 18 lbs. per ihp, and with a vacuum of 27 ins. or better, 12.7 lbs. per ihp. In the turbine an efficiency is assumed,

which is justified by actual experiments, and which can easily be obtained in a very simple machine of the kind.

Pressure of steam between engine and turbine in inches of vacuum.	Per cent. gain over output of engine when worked with high vacuum. The turbine exhausting to a vacuum of 28.5 ins.
0	26.1
4	26.5
8	26.8
12	26.3
16	25.3
20	23.6
24	20.

These figures show an important possibility which should be realized in many exciting plants; and they also illustrate forcibly the value of good vacuum in turbine work, since it shows the large amount of work actually available in these low-pressure ranges by the use of turbines.

Another application of the steam turbine, which promises considerable degrees of economy, is its use as a means of applying the waste heat from gas-engine installations. The best gas engines turn about 20 per cent of the heat from fuel into useful work, the remainder is lost either in the exhaust gases or in the heating of water used to jacket the cylinders and other parts. It should be possible to deliver the exhaust gases through the tubes of low-pressure boilers fed by water which had passed through the jackets of engines. Such boilers could be maintained with a minimum expense, and could deliver steam to simple low-pressure turbines which, with suitable condensers, would deliver a very considerable amount of power. With conservative assumptions concerning the efficiency in applying the heat to water, it can be calculated that 30 per cent could be added in this manner to the power delivered by gas engines.

In operating efficiently at low pressures the steam turbine opens a new field of usefulness which has been practically untouched by existing prime movers, and this advantage constitutes one of the important reasons for its existence. There is, however, another consideration which will play a still more important part in promoting its uses. This advantage is its simplicity. Existing turbines in many cases have given trouble, and an examination of many existing plants might show no improvement in mainte-

nance and attendance expense, compared with engine installations. Such a condition is, however, only temporary, and incident to the newness of the turbine work. Lack of experience in designers and timidity about new apparatus in operating men have in some cases led to annoying difficulties which have caused expense and interruption of service. There are, however, already many turbines operating practically without maintenance expense, and with extremely small labor or attendance, and the time is rapidly approaching when the steam-turbine installation, exclusive of the steam-producing apparatus, will be as simple in operation as the simplest water-wheel plant. In fact there are many difficulties in water-turbine operation which are absent in steam-turbine work; e. g., the troubles from ice and foreign matter in water, and difficulties through variations of head, and difficulties in governing occasioned by inertia of the moving fluid.

In Los Angeles, Cal., a 2000-kw turbine, built by the General Electric Company, is operated daily in parallel with several water-power plants situated at various distant points. It is handled exactly as the water wheels are handled, being kept in parallel with them under all conditions, and used to supply power whenever the water wheels fail to produce it at the desired instant. This turbine is known by the attendants as a hot-water wheel, and has many advantages for this service over reciprocating engines previously used.

CHAIRMAN LIEB: We will postpone the discussion on this paper until we have had the papers by Prof. Rateau and Mr. Hodgkinson. I will read the Rateau paper myself, with your permission, and it will be necessary to abstract it somewhat, as it is quite replete with formulæ which cannot be presented with advantage within the short time that we have allotted for the presentation of the paper.

Mr. Lieb read Professor Rateau's paper.

NOTES ON STEAM TURBINES WITH "FALL OF VELOCITY."

BY PROF. A. RATEAU, *École Supérierure des Mines, Paris.*

Steam turbines with "fall of velocity" are those in which the motor fluid, discharged with a certain initial velocity, v_0, from the nozzles of a distributor, acts several times in succession upon the moving blades, without sensibly changing the pressure, in such a manner that its velocity is gradually dissipated. These successive passages through the moving blades may be made either in several wheels placed one after the other, and forming what we will call a group of wheels, or in a single moving wheel, as in other systems recently invented. Between the passages the flow of steam, which escapes from the moving blades with a certain residual velocity, passes through guide vanes, having for their purpose the changing of the direction of flow in such a manner that its direction will be convenient for the motor action upon the following moving blades. These fixed intermediate guide vanes, designed with semi-circular channels — or nearly semi-circular — do not act as ordinary distributors, since the pressure in them does not vary. Their only end is to turn through a curve of 180 deg. the flow of the steam from one moving wheel to the following; their form is identical with, or at least analogous to, that of the moving buckets.

In the theoretical case where all the blades are semi-circular and where there is no loss of energy by friction or eddies in the fluid vein, we see that the first passage through the moving blades, traveling with a rim velocity, u, reduces the absolute velocity of the steam to the value

$$v_1 = v_0 - 2u.$$

A second passage through the moving blades reduces the absolute velocity of the steam to

$$v_2 = v_1 - 2u = v_0 - 4u.$$

If there are n passages, it suffices then to give to the blades a rim velocity u, equal to $\frac{v_0}{2n}$ for absorbing completely the initial

energy of the motor fluid, from which it follows immediately that the velocity of rotation of the moving blades is inversely proportional to the number of passages, a remarkable property which would permit us to make steam turbines of low speed of rotation, if, for other reasons, this system was not condemned by an insurmountable difficulty — its poor economy — which is what we wish to examine at the present time.

The successive values of the absolute velocity of the steam between the different wheels of the same group, or between the successive passages on the same wheel, constitute a series v_0, v_1, v_2 .... which is really a decreasing arithmetical progression, from which comes the name "fall of velocity" turbines which we will give to this system.

Per unit of mass of the flow of steam passing through the machine — the energy of this flow being proportional to the square of the velocity — the various moving wheels absorb successively the quantities of energy

$$\frac{v_0^2 - v_1^2}{2}, \text{ etc. } \frac{v_1^2 - v_2^2}{2}, \text{ etc.}$$

which is expressed by the general formula

$$2u \left[v_0 - (2n - 1)u\right]$$

n being the number of the wheel in the series considered. The work done by the different wheels decreases then in arithmetical progression.

To our knowledge the idea of turbines with "fall of velocity" came from M. Mortier, who has briefly indicated the properties of which we speak in a communication made the 12th of April, 1890, before the Society of Mineral Industry at Saint-Etienne,[1] following a communication from ourselves upon the Parsons turbine in particular and upon steam turbines in general.

But at this time we did not know the experimental coefficients which would permit the calculation of the losses in the blades; so that it was not possible for us to speak of the practical value of the system.

Seen from the point of view of the method of working of the motor fluid in the moving vanes, these turbines with "fall of

1. *Comptes Rendus mensuels* de la Société de l'Industrie Minerale, April, 1890. Mr. Mortier denoted this system as turbines with "stepped velocities."

velocity" enter into the general class of "impulse" or action turbines, which includes equally the turbines that we call "multicellular," consisting of multiple moving wheels turning in cells placed close together and forming a series of elementary turbines in which the total fall of pressure takes place in successive individual falls according to the discharge sections of the different distributors. Each elementary turbine, composed of a moving wheel and its distributor, gives rise in this system to a fall of pressure and the velocity, v_0, of entrance of the steam into the wheel is in principle always the same, at least for wheels of the same diameter. We propose in this note to compare the properties of the two systems, the "fall of velocity," and "the fall of pressure," principally in that which concerns the economy, and to show that the first is certainly from this point of view very inferior to the second, so much so that one might predict that it could not possibly be successful in practice when account was taken of these defects.

Most of the turbines with "fall of velocity" which have been built are in reality of a mixed nature. They are composed of several groups of wheels separated one from the other by diaphragms. From one group to another there is a fall of pressure, as in the multicellular turbines, while in each group the pressure of steam remains constant, except, to be sure, in the distributor which precedes the group. In certain of these machines there are two groups only of four rings of moving blades each, but these must have been shown to be poor in economy, since the machines made later have only three wheels per group; then more recently two per group. We see then, in fact, that the third ring must do almost no useful work, and that the fourth is plainly harmful. It acts rather as a check to the moving parts.

We will be able to conclude from that which follows what would be the end of the evolution of the turbines with "fall of velocity;" for to lower the consumption of steam to practical values with the turbines with "fall of velocity" it will be necessary to abandon even groups of two wheels and to build them with single wheels in each cell; but then these would be purely "multicellular" turbines.

The irremediable inferiority of the turbines with "fall of velocity" is proved by the losses from friction and eddies of the fluid in the buckets. Without this, the economy would be the same in the two cases and there might not be hesitation in preferring

the system of "fall of velocity" over the other, for it is more simple in construction and permits of the use of a slower velocity of rotation. We have seen that for a group of n wheels replacing a single wheel of the same diameter, the velocity of rotation is with the system of "fall of velocity" reduced in the ratio of 1 to $1/n$ whilst that with the system of "fall of pressure" the velocity of rotation is reduced only in the ratio 1 to $1/\sqrt{n}$.

The Basis of Calculations for the Economy of Action Turbines.

The author has shown, in a paper entitled "Elementary Theories of Steam Turbines" (published in the September number, 1903, of the *Revue de Mécanique*, Paris), the method of calculation which he employs for the study of economy and of which the practical truth is verified by the very satisfactory accord between its predictions and the results of experiments with numerous tur-

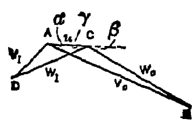


Fig 1

bines, constructed according to his system. It is in the light of this method of calculation, applicable to all species of action turbines, that we will seek what we might expect from the species with "fall of velocity." The method is based essentially upon the fact that the losses of power in a fixed or moving channel are proportional to the square of the relative velocity at the end of the channel, so that the value of this velocity of leaving is a constant fraction λ of the value of the entrance velocity into the channel. If this is not rigorously true, the difference between it and the truth is so small that it may be neglected in the calculations necessary in practice.

In Fig. 1, let ABC be the triangle of velocities at the entrance of a moving bucket (of the helicoidal species) and ACD the triangle of velocities at the leaving of the same bucket.

AB is the absolute entrance velocity v_0 of the motor fluid;

AC is the rim velocity u of the buckets, making with AB an angle α (in the neighborhood of 20 deg. in practice) determined by the final elements of the guide vanes of the distributor;

CB is the relative velocity w_0 of the motor fluid in the moving channel at the entrance of this channel; this relative velocity makes with *AC* an angle which we will call β;

CD is the relative velocity w_1 of the fluid at the time of leaving the moving channel.

Adding to this geometrically the rim velocity $u = AC$ of the blades, we obtain the absolute velocity v_1 (represented by *AD*) at the time of leaving the moving channel.

CD makes with *CA* an angle γ (which in practice lies between 20 and 30 deg.) determined by the final elements of the moving blades.

The role of the moving blades is to reduce the value of the absolute velocity and to modify its direction, from *AB* to *AD*, transforming into useful mechanical work the difference of the kinetic energies of the motor fluid, except that which is lost and transformed into heat by the effect of shocks, friction, and eddy currents in the channels.

The principle of our method of calculation consists in that *CD* is equal to λCB, λ being a fixed coefficient depending upon the the smoothness of the curve and the construction of the bucket.

In practice this value is in the neighborhood of .7. It may fall to .6 or below, if the buckets are roughened, out of line, or with dull edges, and on the contrary it may rise to .75 perhaps, and even higher, when the blades are very sharp, polished, and properly spaced.

In the following we will make the calculations for three values of $\lambda = .7, .75$, and .80, the last being probably above the limit which it is possible to attain in reality. We will designate by ξ the ratio between the velocity u of the moving blades and the entrance velocity v_0 of the motor fluid and we will call this ratio the *coefficient of relative velocity* of the moving blade.

This being settled, let us commence by discussing the ideal case, accessible to the algebraic calculations where the moving blades and the intermediate guide vanes are curved in exact semicircular arcs, in such a fashion that the angles α, β, and γ are equal to zero.

Limit Case of $\alpha = \beta = \gamma = 0$.

In the limit case the triangles of velocity are completely flattened and the velocities are added or subtracted arithmetically.

To simplify the work we will refer all the velocities to the velocity v_0 taken as unity. We will at first take the multicellular turbine, then we will make the calculations for economy of the

turbine with "fall of velocity," and we will limit ourselves to the most favorable case where there are only two passages for the steam.

1. *Multicellular Turbines.*

The velocity of entrance of the steam being $v_0 = 1$, and the rim velocity of the blades being $u = \xi$, the relative velocity of the steam at the entrance to the moving channels is $w_0 = 1 - \xi$; at the leav-

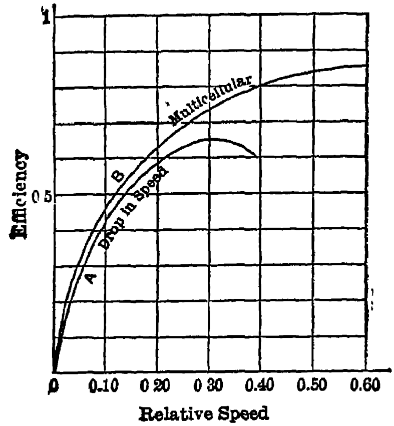


FIG 2.

ing of the moving channel this relative velocity becomes, after our method of calculation:

$$w_1 = \lambda\, w_0 = \lambda\,(1 - \xi);$$

and the absolute velocity of leaving, counted positively in the same sense as v_0, is:

$$v_1 = u - w_1 = \xi - \lambda\,(1 - \xi) \qquad (1)$$

This last velocity is negative for values of $\xi = \dfrac{\lambda}{1 + \lambda}$ less than one-half, and positive for values of ξ greater than one-half.

The impulse F given to the moving blade by a unit mass of steam is equal to

$$F = v_0 - v_1 = (1 + \lambda)\ (1 - \xi) \qquad (2)$$

and the useful work produced per second per unit of mass is

$$T = u\,F = (1 + \lambda)\,\xi\,(1 - \xi). \qquad (3)$$

This last is the internal work done leaving out the external losses we will see later.

This expression of work is maximum for $\xi = .5$, whatever may be the value of λ and the maximum divided by one-half the initial

kinetic energy of the current of steam gives for the maximum internal economy

$$\rho_m = \frac{1 + \lambda}{2} \tag{4}$$

not taking account of the losses in the distributor, which are always very low in turbines with multiple wheels.

However the preceding expression supposes that the velocity v_1 at the leaving of the wheel is not utilized. It is utilized, in fact, in the multicellular turbines, except for the last wheel, in such a manner that the internal economy of these turbines is raised above the figures deduced from the preceding formula. But in order not to complicate the matter we will neglect that in the present case.

We have then for the maximum internal economy of the multicellular turbine "limits" ($\alpha = \beta = \gamma = 0$), in the three hypotheses made with the coefficient λ,

for λ	$=.7$	$.75$	$.80$
ρ_m	$=.85$	$.875$	$.9$

and this maximum is obtained for a coefficient of relative velocity ξ of the blades equal to one-half.

I have already stated these facts in my study of the Pelton wheel, published in 1898 in the *Revue de Mécanique.*

The utilization of the residual velocity v_1 augments these figures by a little less than 1 per cent.

2. *Turbines with "Fall of Velocity."*

Let us take now the case of a turbine with "fall of velocity" with two passages only, having consequently only one series of intermediate guide vanes. This is the most favorable case for this kind of turbine.

For the first passage the circumstances are the same except the value of the coefficient ζ, as in the preceding case, and the velocities w_0, w_1, v_1 have the same formulæ. It is necessary for us to complete the calculation by giving the values of the velocities v_0', w_0', w_1', v_1', for the second passage. Now, the fixed intermediate guide vanes being exactly of the same shape as the moving blades, the velocity v_0' at the point of leaving these vanes is deduced from the absolute velocity v_1 at their entrance as w_1 is deduced from w_0, that is to say

$$v_0' = \lambda v_1$$

λ having the same value. It is necessary, however, to change the sign of v_1 in order to take this positive velocity in a contrary sense to v_0

Thus $$v_0' = \lambda^2 (1-\zeta) - \lambda \zeta \qquad (5)$$

w_0' w_1', v_1' are deduced from v_0' as w_0, w_1, and v_1 are deduced from v_0:

$$w_0' = v_0' - \xi = \lambda^2 (1-\zeta) - \lambda\zeta - \zeta$$
$$w_1' = \lambda w_0' = \lambda^3 (1-\zeta) - \lambda^2\zeta - \lambda\zeta$$
$$v_1' = \zeta - w_1' = \zeta - \lambda^3 (1-\zeta) + \lambda^2\zeta + \lambda\zeta \qquad (6)$$

v_1' being counted positively in the same sense as u.

The total impulse F of the steam in the two passages is for a unit mass

$$F = v_0 - v_1 + v_0' - v_1' = A - B\zeta \qquad (7)$$
$$\begin{cases} A = 1 + \lambda + \lambda^2 + \lambda^3 \\ B = 2 + 3\lambda + 2\lambda^2 + \lambda^3 \end{cases}$$

The internal work per second and per unit of mass is expressed by

$$T_1 = uF = \zeta(A - B\zeta). \qquad (8)$$

It is maximum for

$$\xi_m = \frac{A}{2B} \qquad (9)$$

and the maximum economy for this value of ξ_m is

$$\rho_m = \frac{A^2}{2B} = A\,\xi_m$$

These simple formulas give us the following figures for the three values of λ already taken:

for $\lambda =$	.70	.75	.80
$A =$	2.533	2.732	2.952
$B =$	5.423	5.792	6.192
$\xi_m =$	.233	.235	.239
$\rho_m =$	.590	.642	.701

Thus the maximum internal economy takes place at a value of the coefficient ξ in the neighborhood of .235, and this maximum economy is greatly inferior to that which is obtained in the corresponding case with multicellular turbines, the difference being 28 to 44 per cent of the value of the economy of the turbine with "fall of velocity."

It is to be remarked that for the value ξ_m which corresponds to the maximum in the mean case where $\lambda = .75$:

1). v_0', absolute velocity at the entrance of the second passage, is equal to 25.4 per cent only of the initial velocity v_0; the relative velocities w_0' and w_1' are only 2 per cent of v_0, whilst the residual velocity v_1' after the second passage, directed in the same sense as the rim velocity of the moving blades, rises to 22 per cent of v_0.

2). It is the first passage of the steam which does almost all the work $(v_0 - v_1)$; the second passage gives only a very little $(v_1' - v_0')$; only 5 per cent of that which the first gives.

We would be able then to suppress the second passage without great damage, and in fact, a multicellular turbine having λ equal to .75, and turning with a relative velocity ζ of 234, gives with the formula (3) an internal economy equal to .63, nearly as high as the economy .642 of the system with "fall of velocity;" and, moreover, this value .63 predicates that the residual velocity v_1, which amounts here to .34, is completely lost. With the multicellular system nearly all of it would be utilized and the internal economy would be raised by this fact to more than 7, supposing that 60 per cent only of the energy due to the residual velocity .34 is utilized in the following moving wheels.

Nothing will show better than this remark how very illogical is the system of turbines with "fall of velocity," and even then we have considered only the most favorable case, where there are only two passages.

Case of the Turbines with Groups of Four Wheels.

Let us stop an instant to consider the case of the turbines built with two groups of four wheels and of which some examples of large power have been put in operation. The rim velocity u of the blades is about 100 meters per second and the velocity v_0 of the entrance of the steam is about 850 meters per second. We have then for these turbines:

$$\xi = \frac{100}{850} = .118 \text{ about.}$$

We will calculate from this the successive velocities, in supposing that the channels are semi-circular and that the coefficient λ has the value .75. From that we have, counting v_1 positively in the inverse sense from v_0:

$$\text{First passage} \begin{cases} v_0 = 1 \\ w_0 = 1 - .118 = 0.882 \\ w_1 = \lambda\, w_0 = 0.6615 \\ v_1 = w_1 - .118 = 0.5435 \end{cases}$$

$$\text{Second passage:} \begin{cases} v_0' = \lambda\, v_1 & 0.4076 \\ w_0' = v_0' - .118 = & 0.2896 \\ w_1' = \lambda\, w_0' & 0.2172 \\ v_1' = w_1' - .118 = & 0.0992 \end{cases}$$

$$\text{Third passage:} \begin{cases} v''_0 = \lambda\, v_1' = 0.0744 \\ w''_0 = v''_0 - .118 = -0.0436 \end{cases}$$

We will get from this for the third passage a negative value for the relative velocity in the moving wheel which signifies that the wheel is doing work on the steam in place of receiving work from it; in other words, the third wheel of moving blades is a brake; also this is the same with the fourth. The economy of the machine will be then bettered by suppressing half of the moving wheels and confining them to two per group. The economy would be then

$$2\,\zeta\,(v_0 + v_1 + v_0' + v_1') = .484$$

The real case $\alpha = 20$ deg.; $\gamma = 30$ deg. In that which precedes we have taken the limit case where $\alpha = 0$, and $\gamma = 0$, in order to give simple formulas. Practically the angles α and γ are in the neighborhood of 20 and 30 degs. respectively, and we must see now if these conclusions would need to be modified. We will, however, not establish formulas; that would be much too complicated.

Geometrical constructions, such as those which the author has shown in his "Elementary Theory of Steam Turbines" (*Revue de Mécanique,* September, 1903), will permit us to arrive easily at the determination of the various velocities and economies. Let us take only the results of this determination in the case corresponding to the usual circumstances of practice, where $\alpha = 20$ deg.; $\gamma = 30$ deg.; and $\xi = 0.20$ for the system of turbines with "fall of velocity," with groups of two wheels; and $\xi = 0.35$ for the multicellular system. In the latter we will admit that there is a utilization in the following wheels of two-thirds of the energy contained in the residual velocity at the point of leaving each of them.

The table below groups these results in the three hypotheses: $\lambda = 0.70$, $\lambda = 0.75$, $\lambda = 0.80$.

	TURBINES WITH "FALL OF VELOCITY." ($\xi = .20$) (2 wheels per group).		TURBINES WITH "FALL OF PRESSURE." $\xi = .35$.	
$\lambda = 0.70$	We obtain in the first wheel.	.494	In the wheel..	.7
	Second wheel	.06	⅔ of the residual energy	.06
	Total	.554	Total	.76
$\lambda = 0.75$	We obtain in the first wheel.	.508	In the wheel	.721
	Second wheel	.091	⅔ of the residual energy	05
		.599	Total	.771
$\lambda = 0.80$	We obtain in the first wheel.	.52	In the wheel	.742
	Second wheel	.126	⅔ of the residual energy	.041
		.646	Total	.783

We see that the difference between two kinds of turbines is still large, although it is not so large as in the first case. It is interesting to take account of the variation of economy which comes with a change in the relative velocity ξ. In Fig 2 the curves of economy as a function of ξ are compared under the preceding conditions, supposing $\lambda = 0.75$. The curve *A* is that of the system with "fall of velocity," *B* is that of the multicellular system. We see that this last curve completely envelopes the first, and that it continues to rise still more beyond the value $\xi = 0.3$, which is the value at which the system with "fall of velocity" gives its maximum.

From this results that having given turbines with "fall of velocity" with a group of two wheels, giving a maximum economy, we may realize a notable improvement, other things being equal, by disposing the two wheels of each group in "fall of pressure" (in place of "fall of velocity"), by the interposition of a diaphragm and the ordinary distributor; and, further, the multicellular turbine thus obtained is not of maximum economy, but we would be able to increase this still more by allowing the velocity of rotation to be raised as much as the machine coupled to the turbine would permit.

If it is not possible to increase the number of revolutions per unit of time, we will have always the resource of giving to ξ the desired value by adding new moving wheels which will have, it is true, the inconvenience of complicating the machine and of increasing the initial cost.

Upon the curve *B* we must remark that the internal economy continues to increase beyond $\lambda = 0.5$. This fact is due to the utilization of the residual velocity.

Influence of External Losses.

The external losses from friction of the moving wheels upon the steam in the clearance spaces and of the waste of the steam outside of the buckets are in the turbines with "fall of velocity" less than in the multicellular. The friction is less by reason that, on one part, there are fewer moving wheels and also, on the other part, the pressure of steam in the compartments where they turn is lower and the losses are reduced in proportion to the pressure in the compartments.

But this does not modify sensibly the ratios between the figures established before, since it is easy to keep under 6 per cent and even to reduce to 4 per cent the sum total of the external losses in the

multicellular turbine, if, for example, we will consider a machine of this kind of 2000 horse-power, composed of 25 to 30 moving wheels, and turning at about 1500 r.p.m., we are able to affirm that the friction of the wheels will not exceed 2 per cent, and that the other losses will not amount to over 2 per cent more, making a total of 4 per cent. The fact that the turbine with "fall of velocity" permits us to reduce these losses by one-half even to one-third would not make more than 2 or 3 per cent in its favor which is a little thing beside 20 to 45 per cent to its detriment which, as we have explained before, are due to the great losses by friction and eddies in the currents of steam traversing at a great velocity the first wheel of each group.

From all this we reach the conclusion which we present as the result of the study which we have made of the practical coefficients relating to steam turbines. The species of turbines of action with "fall of velocity," very pleasing in theory, gives place in reality to enormous losses of power, since that, despite all the care given to the form and the construction of the blades, it is impossible to lower below a certain limit the friction of the eddies of the steam in the moving blades and guide vanes.

CHAIRMAN LIEB: We will now proceed with the reading of Mr. Hodgkinson's paper on "Steam Turbine Performance." Mr. Hodgkinson represents the Westinghouse development of the Parsons steam turbine. Mr. Calvert Townley has courteously offered to read Mr. Hodgkinson's paper and he now has the floor.

MR. TOWNLEY: I might say that this paper is largely a collection of a number of tests which have been made, and while the paper is not printed, there is printed a section of it showing in graphic form the result of many of these tests.

Mr. Townley then abstracted the paper.

SOME REMARKS ON STEAM-TURBINE PERFORMANCES.

BY FRANCIS HODGKINSON.

In June of this year, I had the honor of reading a paper before the American Society of Mechanical Engineers, on the subject of steam turbines, and therein endeavored to discuss fully the present status of the turbine art, such that for detailed descriptions of machines, etc., and some theoretical discussions on turbines, I feel constrained to refer to this paper and to briefly extract some of its particulars.

Authors on this subject have devoted so much time to the history of turbines that little remains to be said. It is, however, only since about 1885 that any real work has been done in developing the steam turbine to a practical machine.

A review of the Patent Office records during the early part of the last century shows that many inventors of that time had a clear conception of what constituted good turbine design, but it may be presumed that the mechanical arts were hardly advanced enough to construct the apparatus described.

Popular magazine articles might lead one to believe that in a short time the steam turbine will entirely displace the reciprocating engine. Such statements are based on what the steam turbine has accomplished during its 20 years of life, as compared with the reciprocating engine's life of 200 years.

It must, however, be remembered that it is the necessities of the reciprocating engine builder that have developed the mechanical arts in all their branches that has made the construction of the steam turbine possible. There is little doubt, however, that there is ample field for both the reciprocating engine and the turbine.

In the author's paper before the American Society of Mechanical Engineers, a general discussion was made on the construction of an ideal turbine element. The action of steam in a nozzle and on the buckets was discussed, and a theoretical design of a nozzle was given, the object of which was to show clearly the reason for the divergence.

Actual observations of the behavior of steam in a nozzle are exceedingly complex. All kinds of eddies and swirls take place which are confusing. Dr. Stodola, in his valuable work on steam turbines, describes many observations of nozzles. The writer's work in this direction leads him to believe that it is exceedingly difficult to get readings of pressures in the nozzle that could be taken as representative of the mean pressure at any point of the nozzle measured on its axis.

The turbine has many losses which, although different from those which take place in the reciprocating engine, may, however, come up to about the same aggregate. They are — friction; escape of operating fluid with residual velocity; leakage; spilling, and eddies due to badly formed passages.

There will be found in the paper referred to a brief description of the various turbines that have been commercially manufactured, and an attempt is made to show the advantages that are to be obtained by compounding, so that the total energy of the steam may be fractionally abstracted by the buckets and wheels, these buckets being at the same time permitted to move at a reasonable speed.

As is well known, in the Westinghouse-Parsons turbine, the principle of compounding is carried out to a greater extent than in any other form.

Steam in its passage from the inlet to the exhaust passes through a plurality of alternate stationary and moving blades. The pressure drops take place equally in the moving and stationary, the areas of course of the passages increasing proportionately to the increasing volume of the operating steam.

Steam expanding through stationary passages converts its energy into velocity and does work upon the moving buckets. Similarly, in expanding through these, it again attains velocity and does work by reaction upon the moving buckets and so the cycle is repeated until the exhaust is reached.

This design, therefore, permits low steam velocities which generally approximate 200 ft. per second at the high-pressure parts of the turbine and 500 ft. per second at the low-pressure parts. These velocities are so low that erosion of blades has not been encountered.

Generally speaking, the Westinghouse-Parsons turbine is designed in three barrels. The question is often asked, why three barrels are selected? This question, however, has no bearing what-

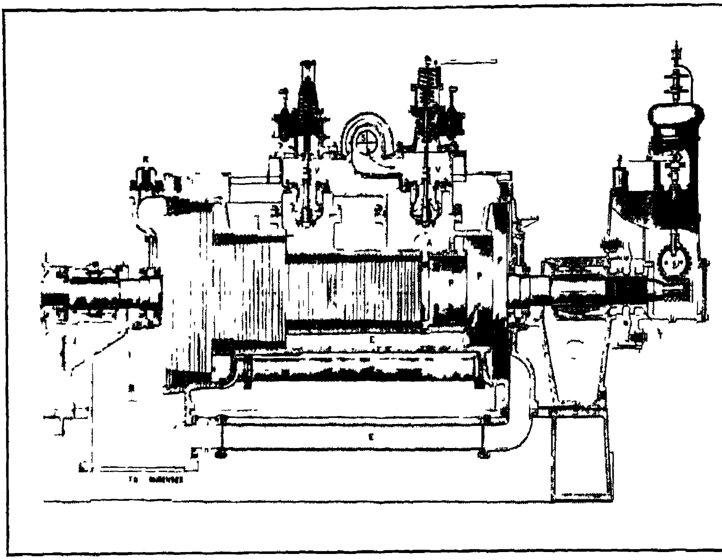


Fig 1

Fig. 8.

soever on the steam distribution of the turbine, as expansion is dealt with in proportioning the blade passages. The reason for the selection is merely a mechanical one. The ideal steam distribution can be obtained just as well with one as with several diameters.

It would be found, however, that if a single diameter were used and speed and diameter of drum were selected that would permit convenient proportioning of blades at the outlet, the blades at the inlet of the turbine would become unmechanically small; similarly, if diameters and speeds were selected to suit the inlet blades, the areas of the blades in the last stages would become unmanageably large. By varying the barrel diameters at several convenient points, corresponding variations may be made in the velocity of the steam, thus permitting blade designs of convenient proportions for both extremes.

In the paper above referred to will be found a general description of this machine, as well as a longitudinal section through a typical turbine of this type, which is here reproduced in Fig. 1.

A facsimile indicator card is given showing the action of the puffs of steam in this turbine, which seems to be conducive of some gain in economy.

The design of the governor is described, and reasons given for this type being employed. The advantages gained are largely due to the continual disturbing influence on the governor parts, such that the friction of rest does not have to be overcome when the governor goes from one position to another on change of load. Also, the admission valve which gives the puffs above referred to is continually in operation, such that it never gets an opportunity to become stuck fast.

The function of what has been termed the "secondary governor valve" is described, the great utility of which will be seen later.

The question of lubrication is one of paramount importance in any machinery, and details of the methods employed have been discussed.

With turbines of this type, excellent results have been obtained by flooding the bearings with oil. Forced lubrication in the ordinary sense of the word is never resorted to.

In some cases of turbines in actual service, where records have been kept, it has been found that the consumption of oil averages one-quarter gallon of engine oil per kw capacity per year. This amount, however, seems somewhat excessive, and the author sup-

poses that a good deal of this oil consumption is the result of spilling when removing the oil from the machine for filtering.

In the paper referred to, much discussion was made on the subject of the economy of the Westinghouse-Parsons turbine, and appended to the paper will be found a table showing the results of various tests under various conditions of operation. In this table, records of 19 different individual machines appear. There is, of course, much advantage in discussing the features of any type of machine, in considering a large number of tests on different individual machines corroborating each other, over considering one test on one machine.

All turbines are thoroughly tested, there being provided accommodations on the testing floor for 10 turbines of large capacity at one time.

The success of a steam turbine is so closely allied to successful condenser apparatus, that it makes desirable some discussion on the latter. Some layouts were made of turbine power plants showing how condensers could be arranged without materially increasing the floor space beyond what is actually required by the turbines themselves.

It is strongly advocated that high vacua are not essential to the successful and economical performance of steam turbines, but, nevertheless, the steam turbine is more susceptible of high vacuum than the reciprocating engine, because the former is capable of expanding down to the lowest limits of condenser pressure which is not practicable with reciprocating engines. Each inch of vacuum above 25 ins. will improve the economy of a Westinghouse-Parsons turbine from 3 per cent to 4 per cent. It has been shown that the capital investment involved by a high-vacuum condenser over one for low vacuum, is repaid by the gain in economy. Except for the greater quantity of cooling water to be handled, a condenser for high vacuum should require no more power than one for low vacuum.

Generally surface condensers are installed in connection with steam turbines because by their use perfectly pure feed water is returned to the boilers, since the exhaust from the turbine is quite uncontaminated with oil.

Since the writing of the paper above referred to, considerable progress has been made in building machines, and it is proposed to give some record of their performances.

Fig. 2 shows the tests on a turbine of 750-kw capacity and of the type shown in Fig. 1. This turbine was designed for operating with high vacuum, nevertheless tests were made without vacuum. The best results were attained under normal operating conditions at about 20 per cent overload. By means of the secondary governor valve before referred to it was possible to carry double load, the steam consumption increasing slightly as the load became higher. At double load, the steam consumption was about 11

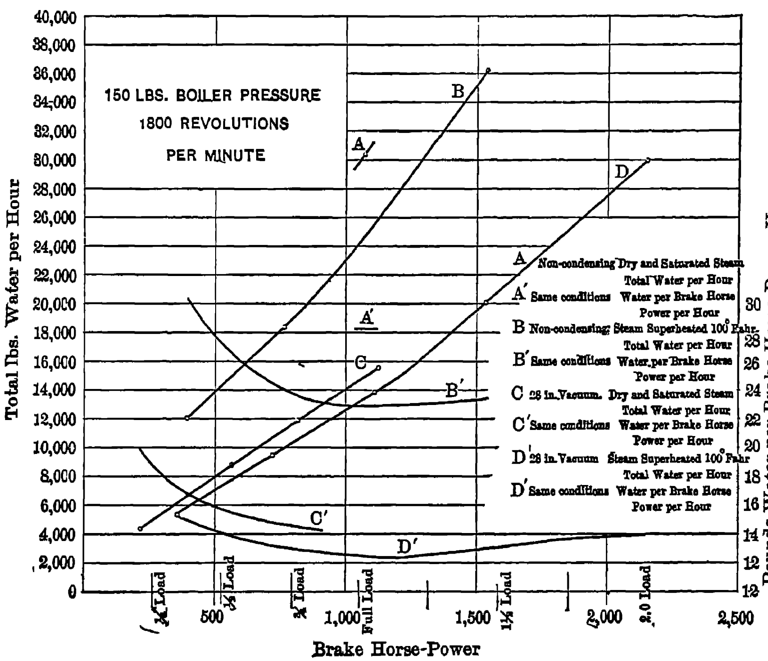


FIG. 2.—TESTS OF 750-KW TURBINE NO. 59.

per cent greater than at the most economical load. This percentage would probably have been less had the vacuum not fallen somewhat, due to the restricted area of the exhaust pipe when carrying such abnormal loads.

The economy of the same machine, tested without superheat, is plotted on the same curve sheet. Such tests, however, were not carried above normal full load. The only reason this was not done was because of the limited time available for making tests on any one machine.

When operating without vacuum and with 100 deg. superheat, it will be observed the best result was about 23 lbs. per brake hp-hour.

Tests were run under these conditions at very nearly 50 per cent overload, when the steam consumption was about 23.4 lbs. per brake hp-hour.

One test was run with neither vacuum nor superheat, showing a full load economy of 28.2 lbs. per brake hp-hour. The average readings of all these tests are shown in Table I.

TABLE I.—750-kw Turbine No. 59.

Operating with 150-*lb. boiler pressure,* 28-*in. vacuum, and* 100-*deg. superheat, at* 1800 *r.m.p.*

Test No.	Ratio of nominal full load	Throttle pressure lbs. gauge per sq. in	Vacuum referred to 30" barometer.	Superheat at throttle °F.	Quality shown by calorimeter.	Speed shown by continuous counter	Load in brake horse-power.	Total net lbs steam condensed.	Lbs steam per B. H. P. hour.
20	.327	154.7	28	100 11	......	1,791.7	854.96	5,439	15 32
19	.656	150 8	28.07	102 64	......	1,797.5	712.03	9,450	13.27
12	1.03	151 4	28.01	99 07	......	1,804.35	1,115.1	13,808.4	12.38
11	1.43	150.9	27.85	99.72	......	1,787 8	1,554.3	20,202.4	12.99
21	1.98	150.1	26.42	92.91	......	1,769.8	2,146.78	29,874	13.91

Operating non-condensing with 140-*lb. boiler pressure and no superheat, at* 1800 *r.p.m.*

Test No.	Ratio of nominal full load.	Throttle pressure lbs. gauge per sq. in.	Vacuum referred to 30" barometer.	Superheat at throttle °F.	Quality shown by calorimeter.	Speed shown by continuous counter	Load in brake horse-power.	Total net lbs. steam condensed.	Lbs. steam per B. H. P. hour.
16	.991	140.1	......	......	99 92	1,771	1,074.7	30,371	28.26

Operating with 150-*lb. boiler pressure,* 28-*in. vacuum, and dry, saturated steam, at* 1800 *r.p.m.*

Test No.	Ratio of nominal full load.	Throttle pressure lbs gauge per sq in	Vacuum referred to 30" barometer	Superheat at throttle °F.	Quality shown by calorimeter.	Speed shown by continuous counter	Load in brake horse-power.	Total net lbs. steam condensed.	Lbs steam per B. H. P. hour.
15	.198	151.9	28.04	......	100.07	1,817	215.64	4,291	19.89
14	.521	151	28.01	......	99 84	1,812	565	8,771	15 52
13	.748	149 8	28.01	......	99 83	1,811	811.04	11,759	14.49
10	1.028	149.5	27.97	......	99 86	1,809	1,126.1	15,506 8	13.77

Operating non-condensing with 150-*lbs. boiler pressure and* 100-*deg. superheat at* 1800 *r.p.m.*

Test No.	Ratio of nominal full load.	Throttle pressure lbs. gauge per sq. in.	Vacuum referred to 30" barometer.	Superheat at throttle °F	Quality shown by calorimeter.	Speed shown by continuous counter.	Load in brake horse-power.	Total not lbs. steam condensed.	Lbs. steam per B. H. P. hour.
23	.366	155 5	......	96 68	......	1,797.4	397.7	12,065	30 33
22	.702	153.5	......	93.94	......	1,776 5	761.06	18,303	24.06
24	1.42	149.4	......	85 33	......	1,759.5	1,544.56	36,248	23.46

It is possible that records of tests on steam engines may be found that will show in some respects a higher economy than here shown, but in this series of tests is demonstrated the enormous flexibility of the steam turbine for operating under all kinds of conditions, and not under any one of these can the performance be said to be bad. There is a great flexibility of overload, surely enough to satisfy the most exacting demands of street railroad work.

It, of course, must be understood that no adjustments are necessary to permit the turbine to operate under all these different conditions. The secondary governor valve is entirely automatic, requiring no hand manipulation whatever.

In Fig. 3 are shown tests on a similar machine operating with 150° Fahr. superheat and both 26-in. and 28-in. vacuum. The machine is precisely the same as the one above described, although tests were not made under so many varying conditions, and are

in this respect not so spectacular. The details of these tests are given in Table II. Another turbine of similar type gave the results shown in Fig. 4, which are detailed in Table III, when

TABLE II.—750-KW TURBINE NO. 60.

Operating with 150-lb. boiler pressure, 26-in. vacuum, and 150-deg. superheat, at 1800 r.p.m.

Test No.	Ratio of nominal full load	Throttle pressure lbs gauge per sq in.	Vacuum referred to 30" barometer	Superheat at throttle °F.	Quality shown by calorimeter.	Speed shown by continuous counter	Load in brake horsepower	Total net lbs steam condensed.	Lbs steam per B H P hour.
9	.482	152.5	25 98	149.2	....	1,818.2	523 5	8,459	16 04
10	924	150 7	25 98	146 6	....	1,820.5	1,025.3	13,516	13 18
14	1.18	148 7	26 02	147.9	....	1,803.2	1,285.2	16,776	13 05
15	1.41	145	25.97	144 2	....	1,803.2	1,536	19,940	12.98

Operating with 150-lb. boiler pressure, 28-in. vacuum, and 150-deg. superheat, at 1800 r.p.m.

Test No	Ratio of nominal full load.	Throttle pressure lbs. gauge per sq. in.	Vacuum referred to 30" barometer.	Superheat at throttle °F	Quality shown by calorimeter.	Speed shown by continuous counter.	Load in brake horsepower.	Total net lbs steam condensed	Lbs steam per B H P hour.
8	.479	151.4	27 99	153 7	....	1,827.4	520 1	7,194	13 85
13	.983	148.6	27 99	153.9	....	1,827 4	1,066 5	12 580	11.79
12	1.24	149 9	27.97	152 2	....	1,807.8	1,345.8	15 370	11.42
11	1.41	149.2	27.76	153 5	....	1,792 9	1,529.3	17,592	11.5

TABLE III.—1000-KW TURBINE NO. 94.

Operating with 150-lb. boiler pressure, 100-deg. superheat, and 28-in. vacuum, at 1800 r.p.m.

Test No.	Ratio of nominal full load.	Throttle pressure lbs. gauge per sq in.	Vacuum referred to 30" barometer.	Superheat at throttle °F	Quality shown by calorimeter.	Speed shown by continuous counter.	Load in brake horse power.	Total net lbs steam condensed.	Lbs steam per B H P hour
5	.503	153.2	28	103.46	....	1,814	545.9	7,884	14.44
6	.928	151.4	27.92	100.6	....	1,800	1,006.2	13,037	12.96
7	1.22	150.8	27.6	100.8	....	1,782	1,332	17,033	12.78
8	1.82	146	26.57	105.8	....	1,764	1.981.2	27,855	14 06

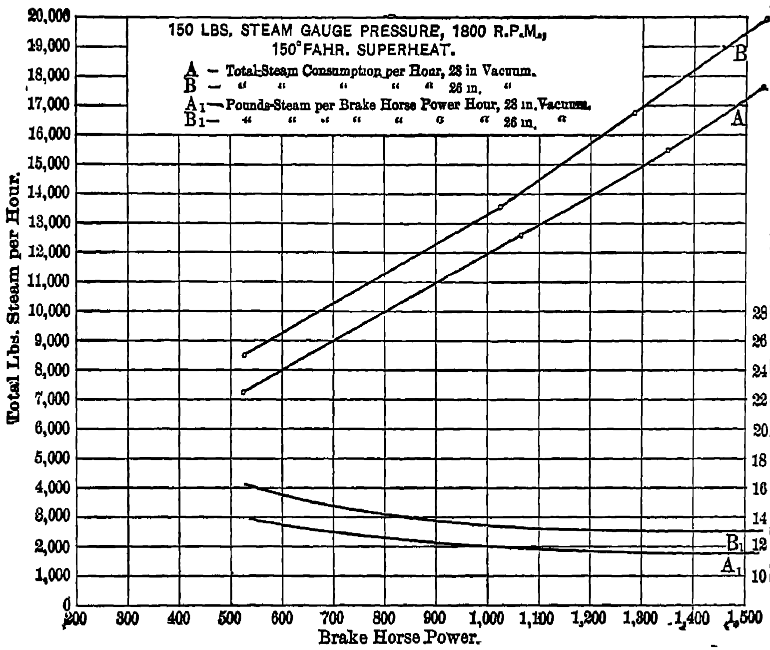


FIG. 3.—ECONOMY TEST OF 750-KW TURBINE NO. 60.

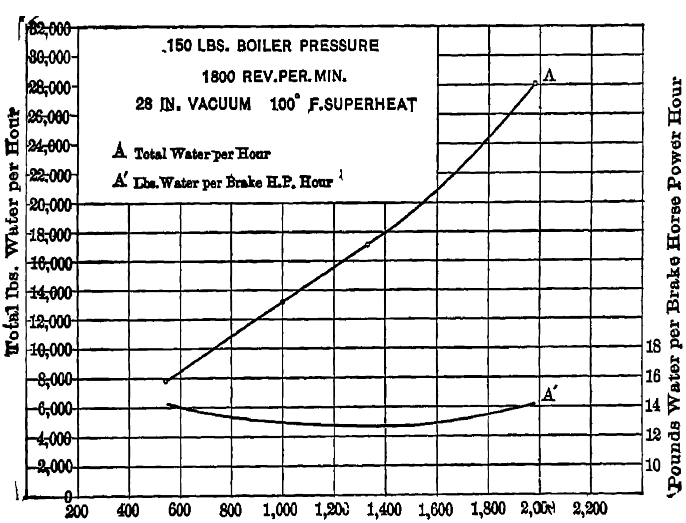


FIG. 4.—ECONOMY TEST OF 1000-KW TURBINE NO. 94.

operating with 28-in. vacuum and 100 deg. superheat. The close agreement between these tests and some of those shown in Fig. 1, where the operating conditions were similar, bears testimony to the general accuracy of the testing methods employed.

Another machine of the same type, operating without superheat and with 26-in. and 28-in. vacuum, gave the results shown in Fig. 5 and Table IV.

TABLE IV.— 750-KW TURBINE No. 95.

Operating with 150-*lb. boiler pressure,* 26-*in. vacuum, and dry, saturated steam, at* 1800 *r.p.m.*

Test No.	Ratio of nominal full load	Throttle pressure lbs gauge per sq. in.	Vacum referred to 30" barometer.	Superheat at throttle °F.	Quality shown by calorimeter	Speed shown by continuous counter.	Load in brake horse-power.	Total net lbs steam condensed.	Lbs. steam per B H P hour
12	.485	155	26 12	......	99.8	1,831	526.1	9,659	18 35
11........	.715	154	26 08	......	99 6	1.824	776	12,901	16.62
10	1 03	152	26.23	......	100	1,815	1,125 6	16,958	15 06
9.	1.41	152.5	26 00	......	99.8	1,786	1,535.7	22,629	14.73

Operating with 150-*lb. boiler pressure,* 28-*in vacuum, and dry, saturated steam, at* 1800 *r.p.m.*

Test No.	Ratio of nominal full load.	Throttle pressure lbs. gauge per sq in	Vacuum referred to 30" barometer.	Superheat at throttle °F.	Quality shown by calorimeter	Speed shown by continuous counter.	Load in brake horse-power.	Total net lbs. steam condensed.	Lbs steam per B H.P hour.
7	.484	155	28.06	......	100	1,824	525.4	8,385	15.95
6	.722	151.5	28.01	......	100	1,826	783.8	11,480	14.65
5	1.029	151.5	28.04	......	100	1,822	1,115.8	15,355	13.76
8	1.43	152	27.85	......	99.8	1,792	1,553.3	21,731	13.99

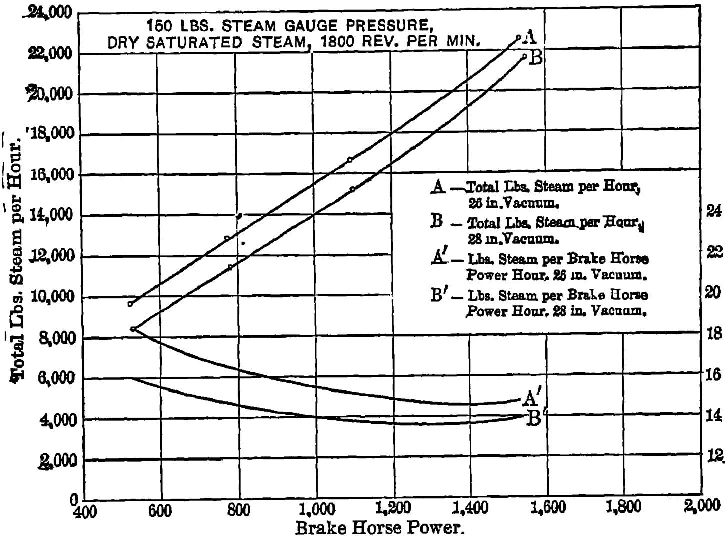


FIG. 5.—ECONOMY TESTS OF 750-KW TURBINE NO. 95.

Of smaller size turbines, Fig. 6 and Table V shows tests on a 400-kw machine

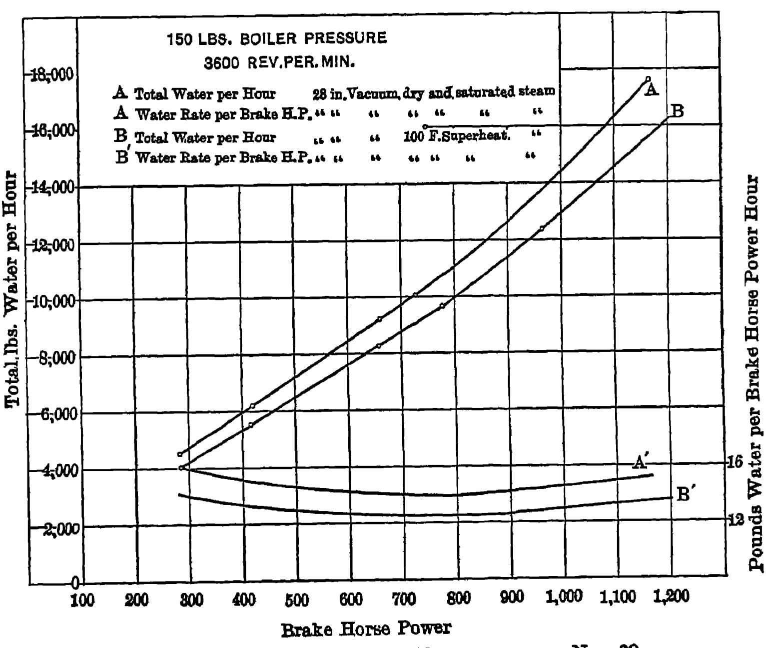


FIG. 6.—ECONOMY TEST OF 400-KW TURBINE NO. 68.

TABLE V.— 400-kw Turbine No. 68.

Operating with 150-lb. boiler pressure, 100-deg. superheat, and 28-in. vacuum, at 3600 r.p.m.

Test No.	Ratio of nominal full load	Throttle pressure lbs gauge per sq in.	Vacuum referred to 30" barometer.	Superheat at throttle °F.	Quality shown by calorimeter.	Speed shown by continuous counter.	Load in brake horse-power.	Total net lbs steam condensed.	Lbs steam per B H P. hour.
6	.483	153.1	28 03	92.5	......	3,561 6	279.4	4,005	14.34
5	.710	153.2	28 03	102.9	......	3,532.2	410.7	5,522	13.45
4	1.13	152 7	28 03	100.25	......	3,502 8	657.3	8,207	12.48
7	1 34	153.2	28 03	93.1	......	3,486	777.6	9,652	12.41
8	1.67	149.6	27 62	100.2	......	3,460.8	967 5	12,377	12.79
9	2 09	152	27.28	99.9	......	3,454.5	1,207.5	16,365	13.55

Operating with 150-lb. boiler pressure, 28-in. vacuum, and dry, saturated steam, at 3600 r.p.m.

Test No.	Ratio of nominal full load.	Throttle pressure lbs gauge per sq in.	Vacuum referred to 30" barometer.	Superheat at throttle °F.	Quality shown by calorimeter.	Speed shown by continuous counter.	Load in brake horse-power.	Total net lbs. steam condensed	Lbs steam per B H. P hour
12	.487	154 7	28 07	2.9	......	3,597.3	281 6	4,468	15 86
11	.717	154 8	28 03	1.8	......	3,571.3	414 6	6,242	15.05
10	1.14	152.6	28.04	2.9	......	3,513 3	660	9,169	13.89
13	1.25	151.6	28.07	.75	......	3,500 3	725.9	10,060	13 85
14	2.01	150.85	27.02	2.3	......	3,496.1	1,165.6	17,632	15.12

operating with 28-in. vacuum, both with 100 deg. superheat and dry saturated steam, and loads up to 100 per cent overload. The close agreement will be noted between these tests and those under similar operating conditions on another machine of the same size tested by Mr. F. W. Dean, of the firm of Dean & Main, of Boston, the results of which have been quite extensively published.

The question is frequently asked, how suitable a turbine is for operating with vacuum during the summer months, but made to exhaust against back pressure during the winter, when the exhaust steam is used for heating purposes.

In Fig. 7 and Table VI is shown the performance of a turbine which is expected to operate against 8 1/2 lbs. per square inch back pressure above atmosphere, as above described. During test, this

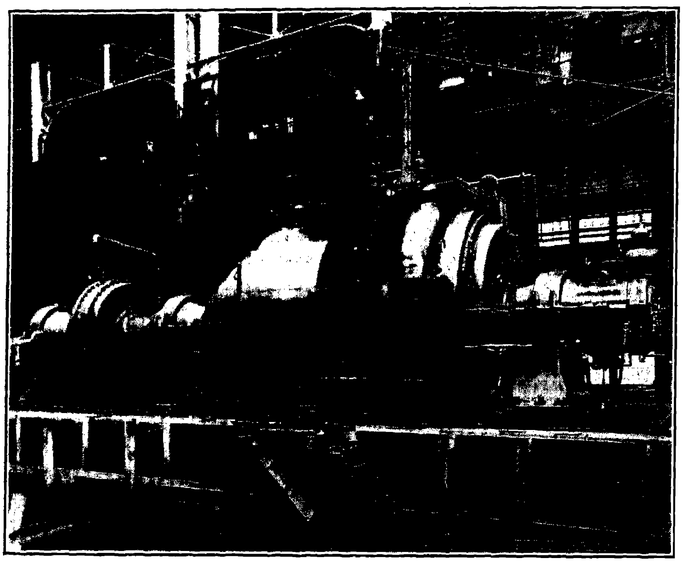


Fig. 9.

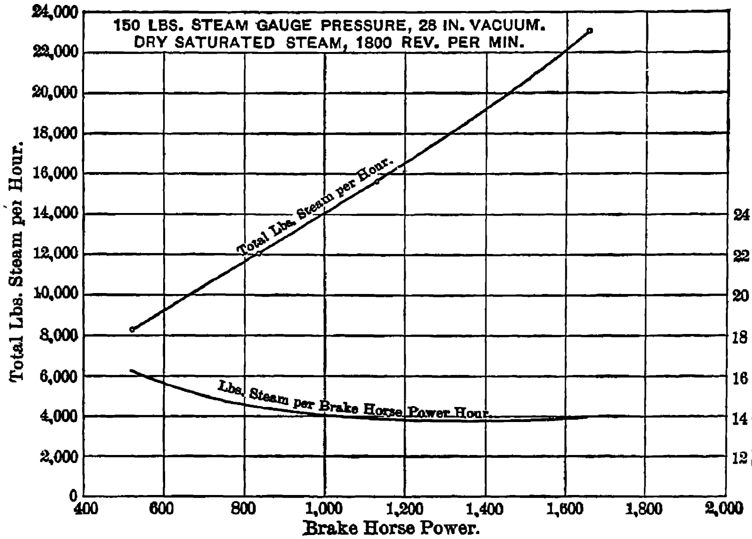


FIG. 7.— ECONOMY TEST OF 750-KW TURBINE NO. 96.

TABLE VI.— 750-KW TURBINE NO. 96.

Operating with 150-*lb. boiler pressure,* 28-*in. vacuum, and dry, saturated steam, at* 1800 *r.p.m.*

Test No.	Per cent of nominal full load.	Throttle pressure lbs. gauge per sq. in.	Vacuum referred to 30" barometer.	Superheat at throttle °F.	Quality shown by calorimeter.	Speed shown by continuous counter.	Load in brake horse-power.	Total net lbs steam condensed.	Lbs steam per B. H. P. hour.
5	.47	147	28.	......	1.0316	1,825	514 5	8,335	16.20
6	.77	144.4	28.	......	.9766	1,820	844.4	12,139	14 37
7	1.03	144.1	27.83	......	1.0876	1,822	1,128	15,747	13.96
8...........	1.52	139.6	27.17	......	.9883	1,786	1,657	23,134	13.97

Operating with 150-*lb. boiler pressure, dry, saturated steam, and back pressure, at* 1800 *r.p.m.*

Test No.	Per cent of nominal full load.	Throttle pressure lbs. gauge per sq. in.	Back pressure in lbs. per sq. in above atmosphere	Speed shown by continuous counter.	Load in brake horse power
10..	1.61	126	9.2	1,754	1.176

turbine carried 1178 brake hp with 9.2 lbs. per square inch back pressure above atmosphere. The arrangement of the condensers, etc., in the testing-room precluded the measurement of the steam consumption while the turbine was operating with such back pressure, but the results of tests under normal operating conditions are here given, in order to show that for the sake of capacity with such a high back pressure, the economy of the turbine when operating under normal conditions was not sacrificed. It will be seen that the turbine is not materially underloaded when operating at normal full load with vacuum.

During the last few months, considerable progress has been made on turbines of 5500-kw capacity, two of which are at this time of writing undergoing tests, with most gratifying results. Figs. 8 and 9 show these turbines on their foundations.

In all of the above described tests, a water brake is used for absorbing the load, in lieu of the electric generator built for use in conjunction with the turbine, which much enhances the accuracy of the tests and eliminates the uncertainty of calibrations of electrical instruments. The brake also permits the test to be made more expeditiously, because of the small delay necessary to adjust the load between tests.

The above few records of performances of turbines are evidence of their all 'round economy.

The fact that 36,000-kw capacity of turbines, the product of one builder, are at this time of writing in successful operation, or in course of erection in the field, is proof of their operativeness.

That power users have confidence in their future is shown by the fact that this one builder alone has 92,000-kw capacity in course of construction, in addition to those already shipped.

Discussion.

Chairman Lieb: Gentlemen, these papers are before you. Mr. K. Sosnowski, a representative of the de Laval Steam Turbine Company in France, has made a number of valuable contributions to the steam turbine question. He has been most particularly interested in the development of the de Laval type of turbine. We would be glad to hear from Mr. Sosnowski.

Mr. K. Sosnowski: I would like to call your attention to one of the principal advantages of the steam turbine with single wheels. and that is the *constant consumption under variable loads*, which is very important. If you take the reciprocating engine, the consumption varies very much under variable loads, sometimes 20 per cent with half load and

sometimes 50 per cent with a quarter load. With the de Laval turbine we have almost the same consumption under all of loads. Another advantage is the *speed maintenance under variable loads.* The variation of speed is perhaps 2 per cent or 3 per cent, if you pass from full load to no load. Mr. Emmet spoke about the use of low-pressures turbines in existing steam reciprocating engines installations. I can tell you that there has been such an application in France for two years, and with good results.

Mr. ROBERT HAMMOND: At what pressure of steam?

Mr. SOSNOWSKI: About two pounds pressure. As to maintenance expenses, we have now the experience of twelve years with 3000 of our steam turbines, and this experience is that the maintenance expenses do not amount, I think, to as much as 1 per cent of the cost of the engine. I would also like to call your attention to the question of *principle.* There are only two principles in steam turbines and there are two great systems of turbines. One is the impulse turbine or action turbine, the first of which was the de Laval steam turbine; and the other is the reaction turbine. Personally I think that the first, the impulse turbine, is best because it presents several very important advantages.

Col. R. E. B. CROMPTON: I presume that I am in the same position as most of us who have listened to the papers, in that we are learners of this comparatively new subject—the economical use of steam turbines. I have listened with the greatest interest, as I am already using steam turbines and manufacturing dynamos for them, and we have orders on our books for large sets for India and elsewhere. I am therefore learning all I can on this subject, and I have gathered much that is useful from these papers. There is no doubt that the introduction of turbines has made the makers of the older class of reciprocating engines look very closely into the best means of increasing their efficiency. On our side, Mr. Parsons has called strong attention to the advantages of very high vacua, and to some extent of superheating the steam, but makers of reciprocating engines have most to gain from the introduction of high temperature of superheat. Much has been done in this direction during the last year or so; so that although at one time the splendid performance of the Parsons' turbine at Frankfort in Germany was equal to the very best, and superior to nine-tenths, of the results obtained from the reciprocating engines at present in use in generating stations, yet by the large introduction of superheat the reciprocating engines have equalled, and in some cases surpassed, the Frankfort figures. This has been greatly due to a better understanding of the functions of high superheat in decreasing steam leakages past sliding surfaces, such as those of slide valves, piston valves, or past the pistons themselves. This leakage is to a great extent volumetric, and is also a function of the pressure. When high superheat is used, the pressure may be considerably reduced without affecting the dryness of the steam; at the same time the volume of the steam in proportion to the thermal units contained in it is largely increased. It therefore follows that by using high superheat in an engine with a given leakage, the thermal units lost by this leakage are reduced. To turn to actual figures, I have personal knowledge that the fact of increasing the

total temperature of the steam from 400 degrees F., corresponding to saturated steam at, say, 210 lbs. pressure, up to a total temperature of 650 degrees F. with a pressure of only 150 lbs., has had the effect of reducing the steam consumption per brake horse-power from 18 lbs. down to the surprisingly low figure of 9 lbs., and this with an engine having no special refinements of valve gear. In order to obtain this high superheat, it is necessary to reconsider the whole boiler question, that the temperature of steam required may be obtained with sufficient regularity. If we take these corrected figures for reciprocating engines, and compare with the best figures for turbines, I think we may summarize the results by saying that at present the most refined turbines are using 20 per cent more steam than the best reciprocating engines using steam at a total temperature of 650 degrees.

There is one other suggestion which I have noticed in Mr. Emmet's excellent paper, that the ideal arrangement to get the highest thermodynamic efficiency from fuel would be to utilize the fuel first in an internal combustion engine, in this way taking out the high temperature heat units and afterward utilize the heat units contained in its exhaust and in the cylinder cooling water by raising steam and using a low-pressure turbine. This combination has no doubt occurred to many of us, including myself. Just before I left England, I was present at the British Association meeting at Cambridge when Dugald Clerk read a paper on his latest developments of the internal combustion engine. He showed that by certain devices he was able to raise the best hitherto recorded thermodynamic efficiency of the internal combustion engine from 28 per cent up to 31 per cent. If to this we suppose that we might get an additional 8 or 9 per cent from a low-pressure steam-turbine, we might get a total all-through efficiency of 40 per cent, which would be a very surprising result. This would be really equal to about two-thirds of a pound of coal per kilowatt-hour.

Prof. FRANK FOSTER: I want to make one remark as to Mr. Emmet's suggestion of using the turbines on the low-pressure side of the reciprocating engine. This has been suggested before, but I think the situation in which it would be of particular use is on board ship, because there the two main points you want are economy and manœuvering power. The reciprocating engine is the more economical down to the pressure of release in the low-pressure cylinder. The turbine, however, allows of the complete expansion of the steam down to condenser pressure, and thus makes up for its poorer economy before release. Hence the maximum economy of steam can be obtained by using a reciprocating engine exhausting at rather less than atmospheric pressure into a steam turbine. Furthermore, the reciprocating engines can be reversed and slowed down with perfect ease, and giving as they do about two-thirds of the total power, they give that manœuvering power which is so necessary in ships. I estimate the increased economy of such an arrangement at from 10 to 15 per cent.

Mr. W. L. R. EMMET: I have not seen Mr. Rateau's paper, and I am not certain that I fully understood everything that has been read from it; but I perceive that in this paper, as in a previous paper which he pre-

sented in Chicago, he endeavors to show that the type of steam turbine with which I have been identified is not the right thing Mr. Rateau in making these arguments bases his ideas on certain mathematical deductions and certain assumptions of possible efficiency. A simple geometrical study of the change of velocity and direction in steam in a turbine has, of course, been made by every intelligent person who has attempted to build steam turbines. But in building steam turbines we find ourselves confronted by a great variety of practical problems which are entirely apart from these mathematical considerations The best steam engines give an efficiency of possibly 60 per cent of the total work available in the steam, and the best steam turbines have given about the same. Thus, there is 40 per cent untouched, and the reason why this 40 per cent is lost is that the problem is restricted by many practical considerations. A single stage turbine of the type which Mr. Rateau has advocated is in itself a very simple affair. It has been found that a jet of steam delivered to a single row of buckets gives a very high efficiency. My experience is that without much care as to the arrangement of the nozzle and the bucket an efficiency of 90 per cent or more can be obtained from such a combination; that is, 90 per cent of the energy can be theoretically obtained with the velocities used and that holds over a wide range of conditions. When, however, we come to design turbines of desirable speeds and adapt them to the best generators, and also adapt them to the highest degrees of expansion of steam, and to the use of largest volumes of steam, we find that this multi-stage type has many practical disadvantages. Theoretically it is good; practically it is only good to a certain restricted extent. On the other hand, the type of turbine which depends for its action on the fall of velocity, as Mr. Rateau states it, has very great practical advantages, and the scope of its application is only limited by the degree of efficiency obtainable in the process of what we call frictional abstraction. Water wheels or water turbines have gone through a long period of development, and during that period of development the efficiency of action of the water on the blades has been immensely increased. Take, for example, the impulse water wheel of the Pelton type. When they were first made they gave an efficiency of about 50 per cent. By a careful study of their action, efficiencies above 80 per cent have been obtained simply by slight changes in the shape of the buckets. Our type of turbine, which diminishes velocity by successive impacts, is naturally a more complicated device than any water wheel which depends on the single impulse. It is also a much more complicated problem than any single bucket steam turbine. Consequently, it is dependent upon design, partly by mathematical calculations as to what its theoretical possibilities are, but more by experimental development. You might as well try to apply mathematics to the curing of a smoky chimney, as to establish this succession of actions with accuracy by mathematical investigation. Of course, every experiment extends our knowledge and enables us to make mathematical deductions which may help us to another experiment. Mr. Rateau, I believe, stated that in a four-wheel turbine arrangement, the fourth wheel must necessarily be a loss and that it was admitted that even the third wheel was disadvantageous.

He is wrong in this. Even with some of the first types experimented with, large results were obtained with the fourth row of buckets, and the reason for abandoning the fourth row in certain cases have been reasons of practical expediency. I am inclined to think that a two-stage turbine, with four rows of buckets to a stage, can be so designed as to be very efficient, but since there are a great number of variables in such a design, its development is difficult as compared with that of a two-bucket arrangement, and the two-bucket arrangement is being pushed largely for that reason. It is simpler to develop. It is probably true that in the future development of the turbine one set of wheels per stage may be used at one pressure and another at another. There are practical difficulties in the pressure diaphragms and on the spaces occupied by the diaphragms, and the length of shaft required, which make it desirable to diminish the number of stages, and this idea of frictional obstruction makes possible that diminution and gives extreme simplification of the turbine.

I have looked at some figures in the table given concerning the performance of the Westinghouse turbine, and I see one figure stated concerning the non-condensing performance of this particular machine, with saturated steam, under the conditions given, and note that twenty-eight pounds per brake horse-power, is given as the performance of this machine under these conditions. This performance corresponds to about forty pounds per kilowatt-hour if that machine were operating a good dynamo. Within a few days I have operated two stages in a machine exactly similar to the one now installed at the Exposition, the first two stages with saturated steam down to the atmosphere, and the steam consumption is thirty-seven pounds per kilowatt-hour, using less than 1000 kilowatt output — a 2000-kilowatt machine being operated at 1000 kilowatt output. That shows that with simply two stages each, with two rows of buckets, an extremely simple device mechanically, a result is given much better than that which has been obtained by this particular Parsons turbine under similar conditions. It is probable that this type of turbine which is now being used with good results will be greatly improved in the future. Our experience has shown immense improvements with slight changes in the construction of the buckets. I believe Mr. Rateau's paper at the beginning stated he admitted that with efficient performance that idea was desirable, although he considered it from the mathematical and not from the practical standpoint. We know its practical usefulness is such as to give it an immense scope on the basis of our existing knowledge, and there is very great prospect of improvements in the future.

Mr. CALVERT TOWNLEY: I might add a further word of explanation in regard to the table in the paper by Mr. Hodgkinson. That shows not tests of two turbines of different sizes, as might be inferred, but several tests on different turbines selected from about fifty. The various tables will show this when printed. I selected these particular tests because most of them are at approximately full load of the machines. The tests tabulated in the paper range all the way from a very light to very heavy loads. It is intended to show freely and without reservation what

economies carefully made practical tests have developed. I want to call attention to the flatness of the water consumption curves. Considerable has been said to-day about the comparative water consumption of the reciprocating engine and the steam turbine. The reciprocating engine, as we all know, is highly efficient at its best point of economy, but falls off markedly for other loads. In contradistinction to this you will note that the steam turbine tests show it to maintain almost a constant economy from half normal rating up to 50 per cent overload, there being a difference only of about one pound of water over this wide range. In comparing the efficiencies of the Parsons turbine and of reciprocating engines this fact becomes very important because it is only a favored few who can always operate reciprocating engines exactly at their most economical points. I will not undertake to go into a theoretical discussion of the design of the turbine.

Col. R. E. B. Crompton: The third and fourth figures apparently are not of the same turbines. Is it actually the case, with the increase of superheat from ninety-nine degrees to 152 degrees, you get 20 per cent reduction in the consumption of steam?

Mr. Townley: These two tests were made on turbines of the same size, and presumably they are close duplicates of each other, as they would be in manufacturing two machines of the same pattern in the same factory. I think it is a fair assumption that the changes indicated are accomplished by the addition of superheat.

Chairman Lieb: We will now consider the discussion on this group of papers closed. We have two papers on electricity supply meters, one by Mr. Caryl D. Haskins on "Integrating Meters," and the other by Mr. G. Ross Green, on "American Meter Practice." These papers are both in print, and with the approval of the Section I will consider the paper of Mr. Haskins as read by title. The paper is an investigation of the numerous groups into which the different commercial forms of meters are divided.

A STUDY OF INTEGRATING ELECTRIC METERS.

BY CARYL DAVIS HASKINS.

There is probably no appliance extensively used in the electrical industry, which can be successfully constructed, with reasonable accuracy, along lines based upon so large a number of fundamentally different physical principles, as the integrating meter.

The engineer who places before himself the broad problem of designing a device which shall leave a permanent record of the total number of units which have passed through it during a given time is free to avail himself of a very large number of starting points.

It is my purpose to make of record in this paper, as many of these starting points as have up to the present time been shown to be worthy of development into an integrating meter. It is also my purpose to so classify these various fundamentals as to place the entire list before you in a defined and tabulated form.

We may divide the integrating meter art into 18 genera, all of which may be classified as coming within six family groups, namely:

Family 1. *Electrolytic Meters.*— Devices dependent upon electro-decomposition or electrodeposit, varying with the current, and leaving a permanent record of the total number of units passed.

Family 2. *Thermal Meters.*— Devices which utilize the variations of heat, corresponding with variations of current, in such a manner as to leave a permanent record of the number of units which have passed during a period of use.

Family 3. *Clock Meters.*— Meters consisting of a clock or time piece, wound either by hand or electrically, with an escapement so constructed as to vary the speed of the clock, or to vary the speed of one clock in relation to a second clock.

Family 4. *Relay or Controlled Meters.*— Devices combining a constant speed mechanism with a governing mechanism which may consist of any form of indicating instrument, the indicating or actual measuring portion of the device determining the number of revolutions made in a given period by the actuating mechanism which does the mechanical work.

Family 5. *Variable Transmission Meters.*—Devices consisting of a constant speed mechanism, either clock or motor, with a transmission mechanism varying the ratio of motion between the constant speed mechanism and the recording mechanism.

Family 6. *Electrodynamic Meters.*—Motors of various forms, designed to vary in speed in accordance with changes in the rate of delivery of energy through their windings.

It will, I believe, be found that substantially all of the integrating meters which have been, or are likely to be, devised, fall within one of these large groups.

In the early days of the art records were rendered generally in amp-hours; today, in America at least, the watt-hour is almost exclusively the unit of record.

Meters have from time to time been constructed to record volt-hours, but their applications are rare, and the demand for such structures has always been limited, and has substantially disappeared with the adoption of the watt-hour.

The very earliest efforts in meter design were naturally directed toward the field of electrolytic meters, the use of electrolysis being the most obvious and direct means of making a proportionate record of the amount of current passing through a given conductor.

It would, therefore, seem appropriate to place the electrolytic family first in the list, and to consider its various genera before passing on to the more important groups.

In the electrolytic group we find but two well-defined genera, but the variety of devices coming within the scope of each of these two genera is very great, and the variations are so considerable as to present the most radical structural differences.

ELECTROLYTIC METERS.

1A. *Meters dependent upon the electrodeposition of metal from one mass to a second mass.*

In certain forms zinc or copper is deposited from one electrode to a second electrode, the loss in weight of the first electrode, or the gain in weight of the second electrode, or both, being utilized to determine the amount of current which has passed.

Mechanical features have been associated with this principle to secure a direct reading record, as, for example, one of the electrodes or both electrodes have been suspended from a spring balance, the change in weight being progressively indicated thereon.

The two electrodes have been so suspended as to reverse the direction of the flow of current by the overbalancing of the weight of one electrode against the other electrode, the two electrodes being suspended from the opposite ends of a beam balance, or the equivalent, the number of oscillations on the beam being counted by any of the well-known methods.

The deposition of a predetermined weight of metal has been made to operate, with or without a relay, a switch to automatically open the service after the passage of a given number of units, this particular form of structure being applied to meters intended for prepayment purposes.

A highly-modified form of this class, dependent upon electrodeposition, is found in that group which depends upon the electrodeposition of mercury, the deposited metal dripping or falling away from the second electrode and forming a quantative measure, indicative of the number of units passed.

Various methods for conveniently measuring the quantity of mercury thrown over have been resorted to, and it will be sufficient to cite the collection of this deposited mercury in a slender tube comparable with a thermometer stem, to indicate a simple and typical form.

It will readily be seen that both the mercury form of meter and those forms of electrodeposition meters which deal with the solid metals can be so modified as to result in continuous or intermittent rotation of mechanical parts.

1B. *Meters dependent upon the electrodecomposition of a fluid—(water).*

This principle has been applied in two general manners to conveniently record the units passed. A tubular receptacle having graduations similar to those of a thermometer, and with the fluid contained therein standing at such a height in the receptacle as to coincide with the zero mark, contains, in its lower portion, two electrodes through which the current, or a proportionate part of the current, is conducted, the current passing from the first to the second electrode through acidulated water.

In this form the amount of water decomposed is theoretically proportionate to the amount of current passing between the two electrodes. The decomposed water escapes as gas, and the level of the water falls in the tube. The difference between the initial condition

and the condition at any subsequent time may be read from the indications upon the scale, in electrical units.

The second modification of this group provides for the decomposition of water, as in the first example, the resulting gases being led away through some form of gas meter, the amount of gas measured being accepted as a measure of the water decomposed and, therefore, of the amount of current passed.

Thermal Meters.

The utilization of various manifestations due to the heat resulting from the passage of electrical current has been accomplished in a very large number of ways in the meter art. I find, however, that thermal meters may be brought within a general classification of three groups.

2A. *Meters dependent upon the evaporation of a fluid, which fluid is subsequently collected by condensation, in a second receptacle.*

This principle has been presented in numerous physical shapes. A sealed receptacle, for convenience commonly of glass, and containing a definite amount of volatile fluid, as for example, gasolene or ether, is so arranged in relation to a conductor, that the heat of the conductor causes the fluid to volatilize at a rate varying with the temperature of the conductor, and, therefore, with the current.

The conductor may be either in the bulb and immersed in the fluid, or external to the bulb, but in close association with it.

The gases of volatilization are led away through a tube forming a portion of the envelope, and condense down into a second receptacle, where the quantity of fluid thrown over may be measured by means of the thermometer stem. or other obvious structures.

Devices of this character have been made to record on a mechanical counting-train, in several manners, a typical form providing two glass bulbs connected by a tube, the entire envelope resembling a dumb-bell in shape, and being pivoted at its longitudinal center. Two heating coils or elements are provided, one in proximity to, or within, each bulb. A transfer switch is so combined with this structure as to cause the current to be measured to pass through the heating element of that bulb which is lowest, only. The lowest bulb obviously contains the greatest amount of fluid, its position having been reached because of the weight of this fluid.

The heat generated in the conductor in the lower bulb by the passage of current causes the fluid in the lower bulb to volatilize and rise to the upper bulb, where it condenses. Thus the fluid from the lower bulb is transferred to the upper bulb, until such time as the preponderance of weight of fluid is in the upper bulb. causing the beam to fall, the bulb and conductor which have been in operation being cut out by the falling of the beam, which also throws the transfer switch. The process proceeds as before.

The frequency of the oscillations of the beam is recorded on a counting-train, and accepted as a measure of the current passing through the heating elements.

It is obvious that other structural modifications may be so applied in connection with this principle as to result in periodic mechanical motion capable of record on a counting-train, in numerous manners.

A number of bulbs may obviously be so arranged in combination with a switch or switches, as to cause continuous rotation of the structure.

2B. *Meters dependent upon the contraction and expansion of solids to a degree, or at a rate, dependent upon the heat produced by the current to be measured.*

The actuating element may be a wire or wires, as in thermal indicating instruments; a thermostat of unlike metals; a conductor and non-conductor having different ratios of thermal expansion; or a tube-like thermostat arm, normally bent, containing a volatile fluid, and tending to straighten by reason of the development of gas pressure when heated.

The actual heating may result from the passage of current through the whole or a portion of one of the elements, or from radiated heat from a fixed element in close proximity to the moving element.

Devices of this class have been less common than those of the previous class, and have been used, for obvious reasons, in combination with transfer switches, alternately throwing one of two similar elements into, and the other out of, the circuit to be measured.

Genera *A* and *B* of the thermal group are best adapted to use in connection with a shunt, the actual current employed being preferably small, the ratio of the utilized current to the total cur-

rent being fixed by the relation of the resistance of the shunt to the measuring element.

2C. *Meters dependent upon the circulation of air caused by the heating of a coil or rheostat in series with the load, the volume or the velocity of the current of heated air being measured.*

For example, a fixed coil so proportioned in resistance and conductivity as to generate a considerable amount of heat (varying with the amount of load) is fixed at the bottom of a chimney-like structure offering free admission of air at its lower extremity, and free egress of air at its upper end. An air vane or anemometer placed within this chimney-like structure results in rotation, the rate of which varies with the velocity of the air current, the motion being transmitted to the counting-train.

There are numerous modified structures which may be applied in the development of this principle. In this group the fixed coil commonly carries the entire current of the circuit.

2D. *Meters dependent upon the production of minus temperatures, by means of the Peltier phenomena.*

A Peltier joint, for example, may be inclosed in an envelope filled with the gases of a highly-volatile fluid. The maintenance of a temperature less than that of the surrounding gases and envelope at the Peltier joint results in condensation at that joint, and a consequent fluid drip, whose frequency is dependent upon the degree of cold produced at the joint, this cold being, through some certain range, a measure of the current passing.

Obviously numerous mechanical alternatives may be resorted to to measure the drip quantatively or in frequency.

Clock Meters.

3A. *A meter consisting of a time piece with a movement of the marine type, an oscillating armature and an electromagnet or magnets being substituted for the balance wheel and hair spring.*

Obviously with this arrangement the variation in strength of the electromagnetic element is equivalent to the lengthening or shortening of the spring (restraining force) controlling the balance wheel, and, therefore, controlling the speed of the clock. This speed may be made to bear a definite relation to the strength

of the electromagnets, and, therefore, to the current passing through some range of load.

3B. *A meter consisting of a clock, generally of the pendulum type, having a pendulum — carrying a soft iron armature, or a permanent magnet, or a coil — oscillating in relation to one or more fixed coils or magnets, the restraining (or, less commonly, the accelerating) effect of the electromagnetic element governing the speed of the clock in relation to the amount of current passing.*

Ordinarily the fluctuations in the speed of the measuring clock are measured differentially, the measuring or variable-speed clock being associated with an ordinary or constant-speed clock. In this type the two clocks are interconnected by a differential mechanism, recording on a dial connected to the differential train the difference in speed between the two clocks, that is the variation in speed of the measuring clock.

Clocks are used as constant-speed motors, or intermittent motors, in numerous meters not falling within the family of clock meters as defined in this paper. Notably, clocks are found in numerous applications, both in connection with relay meters and variable transmission meters.

RELAY OR CONTROLLED METERS.

It seems impossible to subdivide this group into well-defined genera, and it must, therefore, be considered as a family of but a single genus, which we will define as follows:

4A. *Meters in which a constant-speed mechanism of considerable power is controlled in regard to the number of revolutions which it may make in a given time by a balance actuated by the current to be measured, and required to do very little work in controlling the actuating mechanism.*

We may, for example, have a clock, or constant-speed electric-motor, connected through a torsion spring of numerous turns, to a structure similar to the moving coil of a Siemens' dynamometer, just as the manually-controlled button is connected through a torsion spring to the armature of the Siemens' instruments.

The clock or motor is automatically started periodically, as, for

example, once each minute, and continues to run until the torsion spring is wound to a sufficient degree to restore the moving element of the dynamometer to its zero position, the motion of restoration being accompanied by the making or breaking of a circuit, causing the clock to stop. The number of turns of the constant-speed motor are a measure of the torsion required on the spring to restore the armature of the measuring element. This restoration taking place at definite intervals, it is obvious that the sum of the revolutions are a measure of the strength of the current applied through the dynamometer.

As is perfectly apparent, a structure of this kind is capable of almost innumerable modifications.

The actual measuring mechanism may be dependent upon any of those fundamental principles which underlie indicating instruments, and, therefore, may be thermal, electrostatic or electro-dynamic.

Structures of this character are capable of great refinement and have been a field for prolific investigation.

Variable Transmission Meters.

More metering devices have probably been devised which fall within this class, than within any other. The genera are somewhat ill-defined, and tend to merge one into another.

5A. *Meters consisting of a constant-speed mechanism, driving a wheel having spurs or teeth of different lengths, but no two of the same length, and an indicating mechanism of any form, so constructed and situated in relation to the actuating wheel of the constant-speed mechanism as to cause a needle or finger (the position of which is dependent upon the position of the moving element of the indicating mechanism), to engage with a minimum of one and a maximum of all the spurs or teeth on the constant-speed wheel.*

The number of contacts per revolution between the indicating needle and the wheel are counted either by mechanical motion imposed upon the needle by the wheel, or by electrical "makes and breaks," actuating a dial through a relay.

In meters of this group it is obvious that the mechanism can record only at a rate variable by steps, and they are, therefore, not literally integrating meters.

Such meters can record no more than a predetermined load, and no less than a predetermined load, under any circumstances.

If the constant-speed wheel carries 20 teeth, no variation can be recognized of less than one-twentieth of the gross capacity of the meter.

It is sufficiently apparent that a structure of this kind is capable of almost infinite variation, and may be carried out in mechanical structures bearing only the vaguest resemblance one to the other.

5B. *Meters in which the amplitude of movement of a limb, or pendulum, vibrating at a fixed rate, is governed by a stop whose position is determined by a mechanism, taking a position dependent upon the amount of current or energy passing through the device.*

In meters of this group the measure of the units delivered is determined by a summing mechanism, recording amplitude multiplied by the frequency of swing of the finger or pendulum, frequency being constant.

We may, for example, have a clock with a pendulum, or vibrating finger, capable of moving through a widely variable amplitude of swing, and stopped at each oscillation by an eccentrically mounted cam, connected directly to an indicating mechanism, just as the needle is ordinarily connected to such mechanisms.

The amplitude of swing will obviously be greatest when the vibrating finger is stopped by the cam on its shortest radius, which is its "highest load" position, and inversely, the magnitude of vibration will be least when the finger or pendulum is stopped at the longest radius of the cam, which will, in such a structure, correspond to the zero position of the indicating device, and will result in either no vibration of the finger, or a vibration so short as to be incapable of record through the mechanical contrivance utilized for counting.

Like the previous group, meters of this class have a definite maximum limit, but not a sharply defined minimum limit, nor are meters of this group limited to record by progressive steps.

Innumerable paths of development may be followed in applying this general principle to an integrating structure.

5C. *Meters consisting of a constant-speed mechanism and a counting mechanism connected to the constant-speed mechanism only through a variable ratio clutch, ordinarily a friction clutch.*

It may be well to describe three forms.

1) A disc revolving at a fixed speed and driven by a motor or clock, combined with a light-friction pulley free to slide upon, but not to revolve upon, a shaft forming a portion of the counting-train, the position of this shaft and its sliding-contact wheel being at right angles to the plane of, and radial to, the constant-speed disc. The friction contact wheel being free to slide upon its shaft, it is obvious that it may be made to rotate at a very variable speed, dependent upon whether it be in contact with approximately the center or approximately the periphery of the constant-speed disc. The difference in rate is, therefore, determined by the position of the contact wheel upon its shaft, and this position is governed by the coercive force of the indicating mechanism, which may be of any character.

2) A cone or cones may be utilized. In the case of two cones, one is revolved at a constant speed and the second is permanently attached to the counting-train. The two cones are so placed, one in reference to the other, as to have their adjacent sides parallel throughout.

In the space between the two cones is situated an idle friction wheel, transmitting motion from the smaller diameter of one cone to the larger diameter of the other, or *vice versa,* dependent upon its position, the position of the "idler" pulley being determined by the coercive force of an indicating mechanism.

3) A conical-revolving element permanently attached to the counting-train may be made to rock in an arc corresponding with the curvature of its body, making contact with a constant-speed disc or cylinder at its lesser or greater diameter, dependent upon its position, the rocking being accomplished by the coercive force of an indicating mechanism of any character.

All three of these structures will be seen to be modifications of the same general principle, which, indeed, is capable of almost infinite variation.

5D. *Meters in which a thread or ribbon is wound onto a conical drum, revolving at a constant speed, the portion of the conical drum onto which the thread is wound being determined by a guide through which the thread passes, the position of the guide being fixed by the coercive force of the indicating mechanism.*

It will be seen that with such an arrangement the thread will be wound upon a greater or lesser diameter of the drum, and the quantity of thread so wound during a given period may be utilized as a measure of the current, or the quantity may be measured by passing the thread over an idle pulley connected to the counting mechanism.

Like all of its relatives, such a structure is merely typical of a group, and may be modified in a very large number of ways.

ELECTRODYNAMIC METERS.

Whilst it is not my purpose to refer to any particular line of development in either a critical or a commendatory manner within the limits of this paper, it is well that I should record the fact that meters of this family alone have today any vogue in the United States.

It is probable that there are in use in the United States today not less than one and a half million (1,500,000) recording electricity meters, and substantially all of these devices are electrodynamic or motor meters.

I have found it somewhat difficult to properly divide the meters of this group into appropriate and distinctive genera.

Electrodynamic meters divide themselves in ordinary discussion into amp-hour meters and watt-hour meters.

Most of the amp-hour meters would tend to accelerate at a rate proportional to the square of the current, and, therefore, require to be combined with a retarding element, restraining in proportion to the square of the velocity, as an air-fan. There is one highly-important class which constitutes an exception to this rule.

Watt-hour meters, on the other hand, generally would tend to accelerate at a rate directly proportional to the watts, and, therefore, require to be combined with a retarding element varying directly as the velocity, as, for example, the Foucault disc.

With the advent of a comparatively large number of standard voltages, the frequent material variation of potential on certain classes of circuits, and especially with the advent of inductive loads

in connection with alternating-current service, the amp-hour has substantially disappeared from use as the unit of measurement in the United States, and with it, of course, the amp-hour meter has disappeared.

The presence of inductive loads on substantially all alternating-current circuits has rendered it essential that meters shall be literally watt-hour meters, and not volt-amp-hour meters; in other words, they must take no cognizance of idle current.

With these few preliminary statements I may proceed with my classification.

6A. *Meters taking the form of Barlow-wheel motor structures, in which a metallic mass capable of rotation is so situated between the poles of a permanent field, as to be caused to rotate by the passage of current through its mass, from center to periphery, or the equivalent.*

The rotor commonly consists wholly or partly of mercury. In a very simple form a meter of this class may consist of two resultant poles brought into close proximity, with their faces parallel, the space between the polar surfaces being so inclosed as to constitute a flattened annular receptable, capable of holding mercury, the mercury being so confined as to constitute a fluid disc, and being preferably insulated from the polar surfaces.

The passage of current from the center of this disc-like mass of mercury to a greater or less proportion of its periphery, obviously causes the mercury to rotate in the permanent field (which may be created by permanent magnets or electromagnets), the speed of rotation being proportional to the amount of current passing.

6B. *Meters which may be described as revolving D'Arsonval galvanometers, consisting of a wound armature, having a commutator, and commonly a fixed core situated in a permanent magnetic field, in such a manner as to be caused to rotate by the passage of current through the windings.*

Current is led to the armature through the commutator, as in an ordinary motor, and for structural reasons, meters other than those of extremely small capacity are arranged with the armature connected across a shunt in series with the load.

6C. *Meters having a wound field and wound armature, both varying with the load, and both electrically attached to the service wires.*

In its commonest form this class is typically represented by a meter having field coils directly in series with the load to be measured, and a wound armature connected across the system (through the brushes and commutator).

In such a structure the strength of the armature obviously varies with the potential, and the strength of the field with the current. The torque, therefore, varies with the watts. Such a structure, varying in torque directly with the watts, must be combined with a retarding force, varying directly with the speed, which is accomplished in a simple form by the direct attachment of a Foucault disc to the same shaft with the wound armature, this Foucault disc revolving between the poles of magnets having a permanent field.

Within this classification must obviously fall meters having the fields in shunt with the system, and the armature in series with the load, either directly or through a fixed resistance; within this classification would also come meters having field and armature in series, but with this latter arrangement the law of ratio of torque to load would require the application of some form of restraining element other than one directly proportional to the speed.

6D. *Meters for use on alternating or intermittent current only, having a rotating armature, the current in which is induced by the current in the fields.*

Meters of this group take three general forms.

1) A wound armature with short-circuited brushes, the connection between the brushes being made through a greater or less resistance.

2) A structure having field coils in series with the load, constituting a primary coil, a short-circuited secondary coil, commonly of low resistance, and so arranged as to have some angular displacement in relation to the field of the primary, and a revolving armature consisting of a disc or a number of discs of metal, generally magnetic; the progressive polarization of the disc by the series coil and the short-circuited coil causes rotation of the disc by repulsion at a speed varying with the square of the current in the primary.

Such devices require to be connected to a restraining element, the restraining influence of which increases as the square of the velocity; for example, an air-vane or vanes, connected directly to the shaft carrying the rotor.

3) A group commonly known as "Induction Watt-Hour Meters." These consist of a variable field produced by two coils, or sets of coils, one in series with, and the other in multiple to, the circuit under measurement; and a Foucault armature, commonly a disc, cup or the equivalent, situated in the fields produced by the current and potential coils.

By the introduction of electrostructural features, taking various forms, as, for example, a short-circuited secondary, a phase displacement is produced between the waves in the current and potential systems; this creates a revolving field under the inductive influence of which the rotor turns at a speed proportionate to the watts on the circuit under measurement.

In numerous forms the rotor or coercive armature constitutes also the restraining armature. When a disc structure is used, for example, one side of the disc passes between the poles of the coercive field, while the other side passes between the poles of the permanent restraining field. In structures of this character it is desirable and important that the lag between the current and the potential coils shall be 90 deg., or as near 90 deg. as possible.

Under these conditions the coercive force is a measure of the actual applied watts, and not the volt amperes.

If I have succeeded in this brief paper in contributing to the art a clear and comprehensive classification of the various structures and phenomena which have been resorted to in the development of the integrating meter in all its varied forms, I am well satisfied.

I cannot but recognize that there are certain meters which do not obviously and immediately place themselves within any of the groups which I have defined, but it is my belief that substantially all, if not all, may by study be found to come within one of the 18 genera into which I have divided the field of electric meters.

We will now proceed to a brief abstraction of the paper of Mr. George Ross Green, which he has prepared as a representative of the National Electric Light Association. If Mr. Eglin is here I will ask him to be kind enough to read Mr. Green's paper in abstract.

Mr. W. C. L. Eglin presented the paper.

AMERICAN METER PRACTICE.

BY GEO. ROSS GREEN, *Delegate of National Electric Light Association.*

To make this contribution representative of meter practice in America, letters asking for information were sent to a large number of electric lighting companies throughout the United States, and the information received from them has been used in the compilation of the paper. The paper was written in collaboration with Messrs. P. H. Bartlett, B. Currier, J. B. Seaman and W. A. Evans of Philadelphia, Pa.

INTRODUCTION.

When the development of the electric generator and transmission systems had reached a stage which promised a continuous supply of electricity, and when the lamps, motors, etc., had attained commercial recognition, the question of charging for the electrical energy became a matter of first consideration.

The method of charging for gas by meter served as a precedent; but as no thoroughly satisfactory electric meter was available, the contract or "flat rate" system was the only alternative. This system was based on the assumption that the lamps or motors connected would be used a certain number of hours each day.

This system, while still used to some extent, was never considered satisfactory as it encouraged the extravagant and unnecessary use of current; and the invention of a thoroughly practicable and commercial meter became a matter of paramount importance. Some of the best minds in the country for nearly a generation have been devoted to the production of meters, and several of the earlier types placed on the market a decade ago performed excellent service, and are worthy of special commendation, although they have been largely superseded by the more perfect meters of today.

PATENTS.

The following is a complete list of meter patents issued in the United States to July 1, 1904, as supplied by the Patent Office:—

Class 171.—Electricity. Motive Power.

Subclasses.		Patents.
34.	Meters	64
264.	Alternating motor	89
309.	Phase adjustment	93
265.	Direct motor	113
266.	Electrolytic	45
267.	Escapement	30
268.	Multiple-rate	46
270.	Thermal, fluid-expansion	15
271.	Hot-wire	8
272.	Time	30
273.	Variable-radius	87
		620

Class 234.—Recorders.

Subclass.		
55.	Electric meter	33

Single copies of these patents may be obtained for the sum of five cents each from the Commissioner of. Patents, Washington, D. C.; or the Patent Office will furnish a complete set of the papers at the rate of three cents each. Information regarding the number of papers, and the amount of money ordered to be forwarded for a complete set, will be supplied upon request to the Commissioner. By sending a deposit of $5.00 or more, copies of any future patents will be forwarded as soon as issued, at the rate of five cents each.

These patents constitute a complete history of the development of the electric meter in America. They cover almost every conceivable device from the hour-glass type, in which the amount of sand flowing is regulated by the current, and the photographic type, in which the amount of current is indicated by a spot of light falling on a moving sensitized band of paper, to the latest type of meter used today.

The Edison chemical meter was practically the pioneer among the direct-current meters, and maintained the supremacy for a number of years. The Shallenberger meter should be mentioned among the early alternating-current meters. Both of the above were ampere-hour meters, the Edison being of the electrolytic type, and the Shallenberger of the mechanical type.

The ampere-hour meter, both electrolytic and mechanical, is today finding but little favor with electric lighting companies in America; one reason for this being the impossibility of maintaining the voltage absolutely constant over the entire system. For alternating-current circuits the ampere-hour meter is especially unsuitable owing to its inability to accurately measure the energy of inductive loads. No ampere-hour meters are now being manufactured in the United States, the watt-hour meter having almost entirely superseded those originally manufactured. The few still in service are used almost entirely by the smaller companies which, being often without sufficient capital to purchase the more efficient wattmeters, yet recognize the fact that even the ampere-hour meter is superior to the "flat rate" system.

Meters Now Being Manufactured in the United States.

The following is a list of the names and addresses of the manufacturers of meters in the United States, and of the principal types of meters which they produce:—

Diamond Meter Co., Peoria, Ill.

Scheeffer type "F" commutator integrating wattmeter.

Duncan Electric Manufacturing Co., Lafayette, Ind.

Duncan commutator-type wattmeter.

Fort Wayne Electric Works, Fort Wayne, Ind.

Standard and separate seal type "K" wattmeter.
Type "W" wattmeter.
Polyphase type "K" wattmeter.

General Electric Co., Schenectady, N. Y., and Lynn, Mass.

Thomson Integrating Commutator Wattmeters.

Standard types—T. R. W. meter.
Astatic switchboard type.
Street-car type.
Arc wattmeter.
Arc wattmeter, station type.
Two-rate wattmeter.
Battery charge and discharge wattmeter.
Prepayment wattmeter.

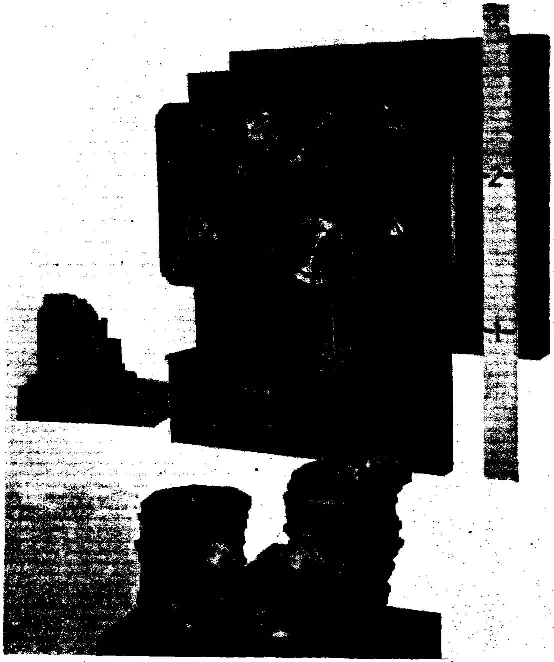


FIG. 1. 30,000-AMPERE METER.

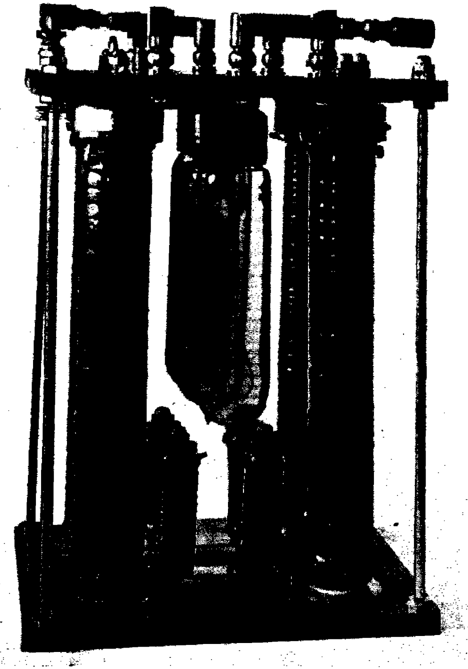


FIG. 6. STANDARD RESISTANCE FOR METER TESTING.

Thomson Integrating Induction Wattmeters.

High torque, type "I."
Polyphase type.

Stanley Instrument Co., Great Barrington, Mass.

Magnetic suspension type wattmeter.
Balanced thrust jewel type wattmeter.

Westinghouse Electric & Manufacturing Co., Pittsburg, Pa.

Type "A" wattmeter.
Polyphase type "A" wattmeter.

The commutator type of meters when properly compensated are applicable to both direct and single-phase alternating-current circuits, and are manufactured of various current capacities for two- and three-wire circuits of any usual voltage.

The induction type of meter is manufactured for two- and three-wire, single-phase circuits; and the polyphase type for two- and three-phase circuits.

No description of these meters is attempted, as the manufacturers are always pleased to furnish, upon application, and free of charge, illustrated catalogues containing full data and descriptions of the meters which they manufacture.

A list of the ampere capacities of meters now manufactured in America is given on page 20. Figure 1 shows the largest meter ever manufactured in America. This is a T. R. W. meter, 30,000 amperes, 550 volts capacity, and is in use on a street-railway system. It is back-connected, having four studs arranged two in multiple. Each stud is 4¾ ins. in diameter and of sufficient length to carry 13 nuts. The current-density in the studs is 840 amperes to the square inch at full load, and in the yoke 1670 amperes to the square inch. The approximate weight is 2000 pounds, and the outside dimensions of the cover are 30⅜ ins. x 19⅝ ins. The relative size of this meter and the standard T. R. W. meter is shown by the cut.

Aims of the Manufacturer.

In America the manufacturer of meters has endeavored to supply an instrument which is thoroughly satisfactory in all particulars and at as low cost as good shop practice will warrant.

Efficiency is not sacrificed to cost, and the cheap and inaccurate meter finds practically no sale in the American market.

The desire of the electric lighting companies to install on their systems only the most efficient meters has been the incentive of the manufacturers; and as rapidly as more improved meters have been produced the less efficient and obsolete have been discarded. The manufacturers have always conducted extensive and costly experiments, and their efforts to produce the best meter possible have, if anything, been increased during the last two or three years. This is evidenced by the fact that most of the manufacturers have placed upon the market during this period meters of new design and construction which are far superior to the older types.

The manufacturer usually welcomes intelligent criticism of his meters, as it is largely from the information thus received that he is enabled to make the improvements desired; and, therefore, the manufacturer and the electric lighting companies have mutually assisted each other in elevating the standard of meter work to its present degree of excellence.

Jewels.

One of the most difficult problems which confronts the manufacturer is the jewel problem. For a long period the sapphire jewel was the best obtainable; and the efforts of the manufacturers were directed towards securing the hardest stones and attaining the highest polish. The Oriental sapphire is at present considered the best obtainable and the manufacturers use no other.

The flat diamond with a ring stone has proven to be an improvement, in many respects, over the sapphire jewel. On light loads, better results have frequently been obtained with a new cup sapphire than with the flat diamond, but this condition does not usually obtain at the end of even a short period of operation. During the last few months the manufacturers have succeeded in furnishing cup diamonds in very limited numbers. It is expected that continued experiments will materially reduce the cost and increase the output of the cup diamonds and that a thoroughly satisfactory jewel will then have been obtained.

Potential Losses.

While the desirability of reducing the potential losses in the meter is appreciated, by both the manufacturer and the company,

it has, nevertheless, been recognized that the best metering efficiency can not usually be obtained with extremely small potential losses, due to the insufficient torque. In America, therefore, these losses are not considered of specially vital importance, since the consequent increased meter accuracy more than compensates for them. The manufacturers are, however, endeavoring to reduce these losses to a minimum, and at the present time the losses in commutator meters are generally 4 to 5 watts per hour at 110 volts, and in induction type meters from 2 to 3 watts in the potential circuit.

Light Load Accuracy.

The ability of the meter to register light loads with accuracy is of more importance than was formerly considered. Of recent years the manufacturers have endeavored to improve the efficiency of the meters at this point by the introduction of adjustable friction compensating devices, and by increasing the torque and decreasing the weight of moving element. The effect of these improvements has been most marked.

Commutator.

Formerly it was the custom to polish the commutator whenever the meter was cleaned or repaired. The polished surface, however, again became quickly tarnished; and the accuracy of the meter, especially on the light loads, was materially affected. It is the present custom never to polish the commutator unless it has been seriously blackened by sparking, etc.; as when once tarnished, the friction remains practically constant, and can be compensated for by adjusting the compensating coil. Since the adoption of this method some years ago, the maintained accuracy of the meters on light loads has been most satisfactory.

Requirements of a Meter.

The primary requirements of an electric meter are, of course, accuracy and the ability to remain accurate. Other considerations, however, also enter into the production of a thoroughly satisfactory and commercial meter.

The following may be considered as some of the requirements of a commercially *ideal* meter, and it is the aim of the manufacturers to approach these conditions as closely as possible:—

Accuracy.

A meter should register within 2 per cent of absolute accuracy on inductive and non-inductive loads between 2 per cent of its rated capacity and 50 per cent overload.—Register accurately on 25 per cent increase or decrease in voltage over its normal rated voltage.—Unaffected by slight changes in frequency and wave form.—Respond quickly to variations of current or voltage.—Should not creep.—Should not be affected by reasonable variations in temperature or barometric conditions.—Equipped with a reliable device for compensating for static friction, and maintaining light load accuracy. The device should not perceptibly alter the calibration on other than light loads.—Should not be affected by strong magnetic fields.—Show no difference in accuracy with the cover on and off.

Ability to Remain Accurate.

Dust, insect and moisture proof.—Unaffected by short circuits on the line.—High torque and light rotating parts.—Permanent magnets should be thoroughly aged and should remain of constant strength.—Constructed so that the ordinary operation of cleaning will not materially affect the calibration.—Dial gears accurately cut.—Workmanship of the best quality.

Design.

Substantially built to withstand the ordinary shocks of transportation and erection.—Light in weight.—Connections not complicated in order to facilitate handling and erection.—As small as possible and of neat design, in order to be unobjectionable when installed in residences, etc.—Operate without noise, humming, etc.—Shunt, field and other losses should be a minimum.—Designed to render tampering impossible.—Provided with large dials to facilitate reading.—Dials should have no constants; but if necessary, the constant should be placed conspicuously on the dial face.—The adjustment devices should be accessible and easily operated.—Adaptable to standard frequencies, or so constructed as to allow of changing from one frequency to another without replacing any parts or removing meter from service.—Accessible adjustment for quarter phasing.—Insulation to be of the best.

Maintenance.

Internal mechanism simple and accessible.—Parts substantially built to withstand wear.—Facilities for removing jewel, shaft or

shaft end, and other parts requiring replacing.—Low cost of repairs and repair parts, which should be of standard sizes and interchangeable.—Special facilities for reducing the cost of repairing and calibrating in the laboratory and in service.

Cost.

The cost should be as low as possible consistent with good workmanship.

The above requirements apply particularly to meters for alternating-current circuits; most of the items, however, apply equally well to meters for direct-current circuits.

It is usually no longer considered necessary that the same meters should be applicable to both direct- and alternating-current circuits, it being considered that the induction type of wattmeter at present on the market is preferable for alternating-current circuits.

In deciding on the make of meter to purchase it is desirable to thoroughly test the meter in the laboratory, although it is hardly safe to be unduly influenced by a laboratory test. In order to determine the most suitable meter, it is necessary to conduct, in addition to the laboratory tests, a series of service tests, covering several months, on a large number of meters in actual service and in different localities, in order that the meters may be subjected to the varying local conditions which exist on the line. During the period covered by the above tests it is necessary to repeatedly test the meters for accuracy and it is usually undesirable to calibrate the meter at such times, as the object to be attained is the determination of the period during which the meter will operate within the limits of commercial accuracy. The minimum period a meter should maintain its accuracy is from six months to a year. As a rule, the meter which has the highest torque and lightest weight of moving elements, will longest maintain its calibration.

Importance of Accurate Meters.

The first consideration in American meter practice is *accuracy*. In the past, station managers have frequently recommended the expenditure of thousands of dollars for the purchase of more modern and economical machinery and suggested the employment of skilled and high-priced labor in order to effect a saving in the generation of current; and yet have often entirely ignored the losses due to the meters which measure this current, although

these losses might even exceed the saving to be attained by the more expensive machinery.

As the electric meter is a type of machine its natural tendency is to run slow, as is evidenced by the averages of thousands of tests. The maintenance of the accuracy of the meters, therefore, brings into the treasury of the company revenue which would otherwise escape.

The testing of meters has also shown that occasionally, through accident, a meter may register fast. The maintenance of the accuracy of meters is an indication of the honesty and integrity of the management of a company towards its consumers.

Objections to the testing of meters have sometimes been made on account of the possibility of losing a few consumers whose meters may be registering far too low. These consumers are a source of loss rather than of profit and the company is either losing money on them or overcharging other consumers by adjusting the rates to compensate for the losses.

It is only by maintaining the accuracy of its meters that the company is enabled to arrive at the equalization of its charges and fix just rates for all of its consumers.

The station manager is usually thoroughly alive to the importance of reducing the coal consumption per kw-hour by the installation of the most efficient machinery, etc., yet if he will take the trouble to investigate, he will find that a 1 per cent increase in his revenue, effected by the testing and calibrating of his meters, is equivalent to several per cent saving in his coal bill, and this should convince him of the necessity of maintaining the accuracy of his meters.

Station Meter Department.

In America most companies that have a sufficient number of meters to justify it, have organized a special department for the maintenance and repair of the electric meters.

Under the work of a meter department may be included all work incident to the electric meter, and it will be considered as embracing the following:—

Installing.—Testing.—Reading.—Bill computing and records.—Repairing and laboratory.

It is not usually customary for a company to so organize its meter department that all work embraced by the above list is included within its province. However, all of this work is so inti-

mately associated that the meter department is in a position to render valuable aid and suggestions in all these branches. For instance, were meters installed by a construction department, entirely independent of the meter department, the meters would probably be installed in a manner which best suited the convenience of the installer, and without due consideration of the subsequent work of the meter reader and tester, which is the most important work in connection with the meters.

As each company arranges its clerical work to best suit its local conditions it will be impossible to satisfactorily discuss the various methods and forms in vogue, and therefore bill computing and records will not be considered in this paper.

Rates.

While it is not within the province of this paper to enter into a discussion of the merits of any system of charging for electrical energy, a brief outline of the prevailing systems may not be out of place.

As previously stated, it was the practice of the smaller companies, before the wide adoption of the meter, to make a flat charge per month per 16-cp lamp connected to the system. This, of course, saved the companies from making a large outlay for meters, but led to abuses and dissatisfaction.

The adoption of the system of charging by meter led to the use of a variety of units, such as ampere-hour, lamp-hour, horse-power-hour and 1000 watt-hours; and a variety of rates per unit were also in use.

The tendency to-day is towards the 1000 watt-hour unit for both light and power. This is recognized to be the standard unit, and all meters manufacturd in America register in this unit.

Some companies have adopted the "Maximum Demand" system of charging, which requires the installation of two meters, an integrating wattmeter for registering the energy consumed, and an ammeter for registering the maximum current used during the period of the bill.

In computing the monthly bill, the reading of the "Demand" meter is multiplied by the voltage of the circuit and by a varying number of hours, depending on the month, and the product reduced to kilowatt-hours is charged for at the rate of, say, 20 cents per kilowatt-hour. The above amount in kilowatt-hours is then deducted from the net registration shown by the integrating meter

and the difference is charged for at the lower rate of, say, 8 cents per kilowatt-hour.

Some companies have adopted the two-rate system without using a "Demand" meter. The energy represented by the product of the lamps connected by a guaranteed number of hours burning per month, is charged for at the higher rate, and the excess used is charged for at the lower rate.

A few companies have adopted a two-rate meter equipped with two separate and distinct dial mechanisms and a clock for automatically causing the meter to register on one dial or the other at predetermined periods of the day. The energy used during the period covering the peak load is registered on one dial and is charged for at the higher rate, and during the remainder of the time the energy used is registered on the other dial and is charged for at the lower rate.

One of the larger companies has a four-rate system, the maximum rate being charged for the first two hours' use per day of the load connected and a lower rate for each additional two hours, as for instance:

15c. per 1000 watt-hours for the first and second hours' use.
10c. per 1000 watt-hours for the third and fourth hours' use.
7½c. per 1000 watt-hours for the fifth and sixth hours' use.
5c. per 1000 watt-hours for all above six hours' use per day.

Some companies allow a discount of a greater or less percentage, depending on the amount of the bill, regardless of the connected load; while others bill at a fixed rate per unit and usually allow no discount.

Many companies require a guaranteed minimum payment per month, and this is charged whenever the calculated amount of the bill is less than this minimum.

Installation of Meters.

Capacity of the Meter.

The selection of a meter of proper capacity to accurately measure the load is a detail of the work to which careful attention is usually given. The life of the meter and its continued accuracy depend to a large extent on the care exercised in this selection, as the aggregate losses otherwise resulting may be very large.

In the larger installations each case is considered separately, as

local conditions frequently require special treatment to secure the most efficient results. The purposes for which the building is to be used and the business of the consumer are also important factors, as the percentage of the connected load used will vary largely accordingly.

The requirements issued by many lighting companies limiting the loads allowed to be connected to the same mains and meter, decrease to some extent the difficulties of accurately measuring the current.

These rules in one case require, separate meters for light and power circuits; separate meters for signs, photographic arcs, charging sets, or other constant loads in excess of certain limits; separate meters for incandescent arc and incandescent lighting where the combined load requires a meter larger than will start on one 16-cp lamp.

By thus separating the classes of service it is usually possible to install meters of such capacities that they will register the minimum loads used on the mains which they control.

Efficient meter practice has demonstrated that it is never advisable to install a meter of greater capacity than is necessary to efficiently and economically register the load on which it usually operates. This is advisable for two reasons: First, a small meter will more accurately register small loads than will a larger meter; and secondly, the investment in meters in service is reduced.

It will be found, therefore, in the majority of lighting plants that the connected load is under-metered. It has been shown by tests with Wright discount and Bristol recording meters that seldom more than 50 per cent of the lamps installed in residences are used at any one time. Usually the maximum number used is not over one-quarter to one-third, and therefore it is the practice to install for residence lighting, meters of capacities of 50 per cent or less of the connected load. Occasionally, during social functions, etc., the meter must withstand a large overload, but the losses, due to these overloads, which are short and infrequent, are more than compensated for by the greater accuracy obtained on the light loads.

In small stores, saloons, etc., where usually all of the lamps connected are burned at one time, a meter is installed having a capacity about equal to the connected load. If, however, a store has an installation of 40 lights which are burned one or two hours each evening, and during the remainder of the time only one or

very few lamps are used, it would be considered preferable to install a 15-ampere, 2-wire meter rather than a 25-ampere, 2-wire meter. The controlling factors in the selection of a meter for such installations are the losses due to overload in the one case, as compared with the losses due to light loads in the other.

For signs and other sources of constant load a meter of a rated capacity equal to the load, or, preferably about 20 per cent greater, is installed. This also applies to motor circuits and particularly to alternating-current and elevator motors, the meters installed for which have a capacity from 25 to 50 per cent greater than the nominal horse-power of the motors. In some of the larger installations of this character the maximum and minimum current used is determined, and the meter most suitable to the requirements is then installed. On the polyphase light and also power circuits some companies install a single-phase meter on each phase while others prefer to use polyphase meters,—the latter practice being preferable, especially for power circuits.

In theaters, churches and other buildings of a like character it is sometimes impossible to install a meter which will accurately measure all the loads and start on the minimum loads, and in such cases the circuits are frequently divided and several meters are installed. In such buildings it is customary at times, through the day and during the hours of cleaning, to use only a very small percentage of the lamps. To endeavor to measure the current used by these lamps with a meter of sufficient capacity to accurately measure the entire installation involves a loss which can be largely saved by using the separate circuits and two or more smaller meters.

On very large installations, such as department stores, etc., it is customary with some companies to install one or more of the largest capacity meters, while others will install a number of smaller meters, each controlling separate floors or departments. The latter method is considered the better practice; for while the investment costs and potential losses of the smaller meters are greater, the losses during light load periods are reduced, and the possibility of losses occurring due to the large meters registering low, or, becoming defective and failing to register, are very largely reduced. The small meters can also be more easily tested and the reason for any fluctuations in the bills can be readily located and explained.

Location of the Meter.

The location of the meter is a matter to which careful attention is usually given. The continued accuracy of the meter is dependent, to some extent, on its location, and as the meter registers the income of the company, and the meter board is in many cases a distributing point where fuses and switches are located, it is to the interest of both the company and consumer to secure a location which is entirely suitable.

The general requirements are, that the location shall be dry, free from dust and vibration, not in close proximity to gas pipes, water pipes, or heaters, nor subjected to extremes of temperature. The location should also admit of the erection of the meter on a solid support and be accessible at all times.

It is not always possible to obtain all of these conditions. A substantial vertical support, such as an outside wall, allowing the erection of the meter, five or six feet from the floor and with sufficient clear space all around the meter to permit of easy inspection and testing, is, however, usually obtained.

In selecting the location of the meter, kitchens and the upper floors, especially bathrooms, bedrooms, small closets, and any location where the meter reader or tester would be interfered with, or, the consumer disturbed, are avoided.

Installing the Meter.

It has been evident for some time that in order to lessen the cost of maintenance and to decrease the possibility of tampering, the service and meter wiring should be installed in a more permanent manner and be of greater stability than was formerly the custom.

The former methods of installing meters, with open wiring and uncovered cutouts and switches on both the service and house side of the meters, is therefore no longer considered safe or desirable by many companies.

The design of the installation should be compact and should be standard, or rather the several designs required to suit varying conditions and meters should be standard, in order that all meters can be erected in substantially the same manner; and it should also be of such a character that the several parts are interchangeable and can be used again in the event of the service being discontinued and the meters removed. In the design should also be

combined durability, flexibility, as low first cost as possible, and a minimum of opportunities for tampering, etc.

The materials used should be of the best quality obtainable, as the service and meters are frequently located in cellars where dampness and generally worse conditions exist than in other parts of the building. The work should be performed by skilled mechanics, possessed of good judgment and a fair knowledge of the meter.

The arrangement should be such that the greatest stability and safety possible are obtained in order to insure a continued and uninterrupted service, and to render unquestionable any possibility of fire occurring due to defects in this part of the electrical equipment; as, owing to the location, it is usually subjected to rougher usage than the balance of the installation, and is more often surrounded by inflammable material than similar apparatus in other parts of the building.

Meters are usually fastened to a board secured to a solid vertical support and in the larger installations they are frequently mounted on marble or slate panels. It is customary to install a cutout between the service and the meter. The cutouts used are of various designs, the tendency being to have them enclosed and some of the companies are using an iron box, so arranged that it can be sealed in the same manner as the meter.

Some companies have also adopted a series of standard meter boards, some cuts of which are shown. The different parts of these boards are assembled and wired in the shop and sent to the consumer's premises ready for erection.

When installing the larger sizes of meters special arrangements are frequently made to facilitate the work of the tester when connecting the instruments, etc.

Referring to the accompanying illustrations, Fig. 2 shows a type of single meter installation for capacities up to 75 amperes, arranged for the erection of additional meters, showing method of connecting to underground service. No wiring is exposed from the service to house switch. Fig. 3 is an installation of two induction meters for a two-phase, three-wire circuit, showing a three-pole interlocking house switch. Fig. 4 is an installation of three three-wire meters and one two-wire meter for light and two two-wire meters for power, in a store.

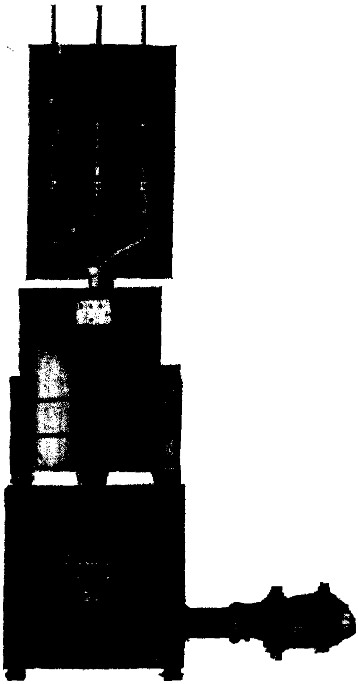


FIG. 2. SINGLE METER INSTALLATION.

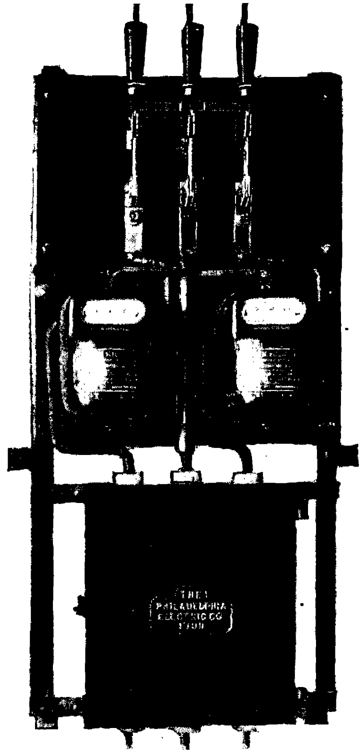


FIG. 3. INDUCTION METER INSTALLATION.

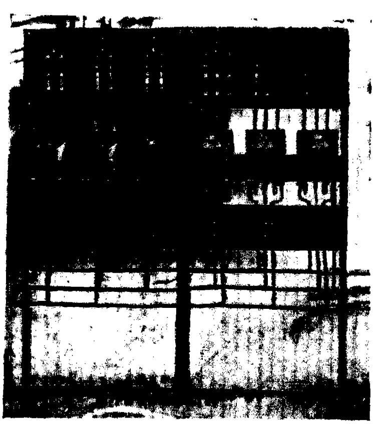


FIG. 4. TWO- AND THREE-WIRE METER INSTALLATION.

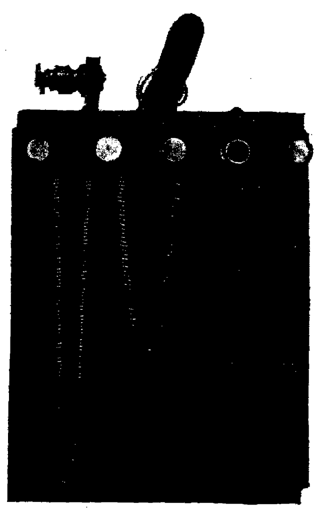


FIG. 5. PORTABLE STORAGE BATTERY FOR METER TESTING.

Testing Meters.

Experience has demonstrated that when the meter is received by the purchaser, it is not always in calibration, and all meters are therefore usually tested in the laboratory. Some companies install the meter and then retest it, as the meter is thus calibrated for the actual conditions under which it must operate. Other companies prefer to rely entirely on the laboratory test, and after installation, send an inspector to determine if the meter is operating. It is questionable whether this latter method is preferable to the former, as experience has demonstrated that a meter will not always maintain its calibration during transportation and erection.

It is desirable to have the installation test made shortly after the current has been turned on, as experience has shown that short circuits and accidents, which may affect the calibration of the meter, frequently occur on new installations. This is considered an argument in favor of testing the meter after it is installed rather than relying on the prior test made at the laboratory.

Periodic tests are made at intervals of one month, three months, six months and a year, depending on the amount which the meter has registered. This, however, is not the only determining factor, for while some meters may not require testing until the disc has rotated from five hundred thousand to one million revolutions, or more, others may require more frequent testing, due to excessive vibration or other local causes. It is frequently customary to test monthly all large meters which register large amounts. These meters, if in error, are usually found to be registering low, and a one per cent loss in them is equivalent to a much greater percentage loss in smaller meters; and furthermore, any accident such as an open circuit in the armature, etc., causes a much greater loss to the supply company than similar accidents in smaller meters.

The periods for testing other meters are determined from the results of former tests, and from close inspection of the amounts registered. From the data thus collected it is frequently found advisable to change the period of the test for a particular meter—transferring it from one period to another.

If consumers complain of excessive charges the meter is usually tested if a consideration of the conditions warrant it.

Special tests are also made where the bill shows an unusual in-

crease or decrease; the results of these tests often determining the period of the next test, as explained above.

It is usually customary when testing meters showing a "straight line curve," to test on loads of about 5 per cent and 75 per cent of the rated capacity of the meter on alternating circuits, and on loads of about 10 per cent and 75 per cent on direct-current circuits. In the case of complaint and special tests, however, the meters are usually tested on loads of 5, 25, 50 and 100 per cent of the rated capacity of the meter, in order to more closely ascertain the degree of accuracy throughout the range; thus enabling the company, by considering the loads most frequently used, to more nearly determine the actual error, if any exists.

Method of Testing.

For testing meters in the meter shop or laboratory it is customary, particularly with the larger companies, to install a special switchboard and apparatus for obtaining the requisite voltages and currents, and also special racks upon which one or more meters may be erected and calibrated. One attendant operates the switchboard, and by the use of rheostats, etc., maintains the exact current and voltage required.

For the testing of meters in service three methods are in vogue—

First—Testing with standard instruments.—Second—Testing with standard resistances. Third—Testing with standard meters.

For testing direct-current meters by the standard instrument method it is customary to employ a portable voltmeter and ammeter or preferably a milli-voltmeter and shunt calibrated to read in amperes.

The voltmeter is connected to the circuit as near as possible to the points to which the potential circuit of the integrating meter is connected, and the shunt of the milli-voltmeter is connected in series with the field coils of the integrating meter. The necessary load for testing the meter is obtained by the use of portable lamp banks or other resistance, water rheostats, or, by the use of the load on the consumer's premises, and also from portable cells of storage battery (Fig. 5). The revolutions of the meter are timed by means of an accurate chronograph.

For testing meters on alternating-current circuits, an indicating wattmeter is preferably used and the load can be obtained as above, with the exception of the battery, which cannot, of course, be used. A small portable low-potential transformer is, however,

FIG. 7. STANDARD TESTING METER.

sometimes used by some companies. For testing these meters on light loads standard lamps are frequently employed.

The standard resistance method consists in the employment of a specially constructed resistance (Fig. 6) calibrated in amperes or watts for various voltages, the corresponding values being tabulated. By connecting the resistance across the line and in series with the field coils of the meter to be tested and ascertaining the voltage by means of a voltmeter, the load on the meter is at once determined. This method is usually employed only for testing the smaller sizes of meters, and the boxes are so constructed as to permit of testing the meters on both light and large loads.

The standard meter method consists of the use of a specially calibrated portable meter connected in series with the meter to be tested. Originally it was customary to employ an ordinary meter specially calibrated as a standard for this purpose, but owing to the slight torque and consequent liability to inaccuracy on light loads, this method was found to be unsatisfactory.

Mr. W. S. Mowbray, of the Edison Electric Illuminating Company, of Brooklyn, N. Y., has designed a special standard meter (Fig. 7) so constructed that the torque at all loads is practically the same. The objectionable features have thus been eliminated and testing by this method is both rapid and accurate. By the use of a telephone receiver connected to the standard meter it is possible for one man to perform all the work incident to the testing of the wattmeter.

The ranges of his present standard meter are 1, 4, 20 and 80 amperes and 115 and 230 volts; and the standard can therefore be used for testing all meters up to 100 amperes capacity or even somewhat larger.

Tools.

It is extremely desirable to provide the meter tester with a full equipment of tools for the proper performance of his work, and it is preferable that the company should supply these tools and exchange for new ones any which become worn or damaged. Under these conditions there is no excuse for the tester being provided with any tools unfit for the work.

Equipping the tester with proper tools results not only in more efficient work, but incidentally has a moral effect upon the consumer, who naturally places more confidence in the test when the tools and instruments are kept in the best possible condition.

The General Electric Company supplies a pocket kit of tools which is found extremely useful. In addition to this kit the tester should be supplied with the necessary pliers, tweezers, screw-drivers, fine files, monkey wrench, sealing press, magnifying glass, brushes, needles, alcohol torch, connectors and special leads for properly performing the work. A small rubber syringe is frequently used for blowing dust out of the commutators, etc.

Test Record.

It is customary to enter the records of the test on specially printed forms. That used by one of the companies is shown opposite. This form is arranged for only one test.

Each company arranges its test records to best suit its local conditions, very few companies using exactly the same form.

Instead of issuing a separate card for each test, some companies prefer to use one card for a number of tests. These cards are then usually filed according to the company's serial numbers of the meters and serve as a card index of the tests.

Code.

In order to lessen the work of recording the adjustments, etc., various codes have been adopted, one of which is as follows:

A.	Armature.	M.	Magnets.
B.	Brushes.	N.	Wing nut.
C.	Commutator.	O.	Cover (outside).
CC.	Compensating coil.	P.	Phasing coil or coils.
D.	Disc.	Q.	Shunt circuit, secondary.
E.	Shaft end.	R.	Resistance.
F.	Field coils, main coils.	S.	Shaft.
G.	Counter gearing, counter.	T.	Top bearing.
H.	Hands on counter.	U.	Wiring (size, state, etc.).
I.	Impedance coil.	V.	Vibration.
J.	Jewel.	W.	Worm.
K.	Compensator.	WW.	Worm wheel.
L.	Level, leveled.		

The terms generally used on the test pages or cards have also been abbreviated, such as *Adj*, adjusted; *Br*, bridged, etc.

TEST-PAGE NO. A

SERIAL NO. .... SHOP NO. .... DISTRICT ....

ROUTE .... PERIOD .... DATE .... 190...

CONSUMER'S NAME ....

ADDRESS ....

OCCUPIED AS ....

LOCATION OF METER { ERECTED ON .... / IN .... / OCCUPIED AS ....

NAME .... TYPE .... FORM .... CAT. NO. ....

CAPACITY { .... AMPERES / .... VOLTS / .... WIRE

CONSTANT { DIAL .... DISC .... / TEST .... COILS .... / BILL ....

POTENTIAL .... VOLTS .... INFORMATION CARD NO. ....

CIRCUIT .... WIRE .... VOLTS AT METER .... PHASE ....

LOAD { LAMPS, ... 8 C. P. .... 16 C. P. .... 32 C. P. .... BASE / MOTORS .... ARCS .... FANS .... / MISCELLANEOUS

WATTMETER NO. .... VOLTMETER NO. .... AMMETER NO. ....

MILLI-VOLTMETER NO. .... S. L. NO. .... STOP-WATCH NO .... SEAL ....

TIME ENTER — TEST BEFORE ADJUSTMENT — DIALS

%		VOLTS	AMPERES	REV'S	SECONDS	STANDARD WATTS	METER WATTS	%
5								
25								
50								
100								

TIME LEAVE — TEST AFTER ADJUSTMENT — DIALS

5								
25								
50								
100								

LAMPS REQUIRED TO START, BEFORE ADJ. .... AFTER ADJ. ....

REASON FOR TEST .... NEW .... EXCHANGE .... METER ....

ADJ	A	B	C	CC K	D	E	F	G	J	L	M	f	ñ	c	T	U	V	BOX SEAL

REMARKS: ....

....

....

....

....

TESTED BY .... ASS'T. ....

LAST TEST: PAGE NO. .... DATE .... SEAL LEFT .... SEAL FOUND ....

Meter Serial Numbers.

Where a large number of meters are in service it has been found advisable to adopt a system, of serially numbering them and not depend on the manufacturer's numbers, which are not consecutive so far as the individual lighting company is concerned. Some companies number their meters from unity up, irrespective of the sizes and makes of the meters.

The Philadelphia Electric Company has adopted the following system of numbering meters serially:

The number of the meter is stamped on an aluminum plate with a Roover embossing machine, and the plate is then riveted to the meter cover.

The number consists of two parts separated by a letter designating the make of the meter. The first part, called the "capacity number," indicates the capacity of the meter in volts and amperes, and also if two- or three-wire. The second part is the serial number proper, each size of each make of meter being numbered serially from "1" up.

The capacity number always consists of three figures, except in the case of three-wire meters, which are all 220 volts, and therefore the number corresponding to the voltage is omitted.

The voltages in round numbers, and the number designating each, are as follows:

Volts.	Designating Number.
100	1
200	2
500	3
1000	4
2000	5
5000	6

The letters designating the make or name of the meter are as follows:

K = Fort Wayne, type K wattmeter.
S = Stanley wattmeter.
T = Thomson recording wattmeter.
W = Westinghouse wattmeter.
Etc.

The ampere capacities of all meters manufactured in America are arranged in serial order and numbered consecutively. The

ampere capacities of the meters and the corresponding "capacity numbers" for the different voltages are as follows:

Capacity, amperes	Two-wire, 110 volts	Two-wire, 220 volts	Three-wire, 220 volts	Two-wire, 500 volts
3	101	201	1	301
3½	102	202	2	302
5	103	203	3	303
7½	104	204	4	304
10	105	205	5	305
15	106	206	6	306
20	107	207	7	307
25	108	208	8	308
30	109	209	9	309
40	110	210	10	310
50	111	211	11	311
60	112	212	12	312
75	113	213	13	313
80	114	214	14	314
100	115	215	15	315

Other ampere capacities of meters manufactured in America are as follows:

120, 125, 150, 200, 250, 300, 400, 450, 500, 600, 800, 1000, 1200, 2000, 2500, 3000, 4000, 5000, 6500, etc.

For preserving a record of the meters a card index is used. Cards having the same capacity number are filed together serially for each make of meter, the different capacity numbers being separated by guide cards. The cards are arranged under "Meters in Service," "Meters in Stock" and "Meters Ordered," and by this means the total number of every size and make of meters in service, meters in stock and meters on order can readily be determined within a very few minutes.

Following are examples of numbering:

108 K 12 represents 110 v., 2 w., 25 amp., Ft. Wayne type "K" meter No. 12.

211 S 22 represents 220 v., 2 w., 50 amp., Stanley meter No. 22.

303 T 32 represents 500 v., 2 w., 5 amp., Thomson meter No. 32.

5 W 164 represents 220 v., 3 w., 10 amp., Westinghouse meter No. 164.

Meter Reading.

Meters are usually read once each month except in special cases where it is necessary to render bills weekly, etc. Where a small number of meters are in use it is usually customary to read all the meters during the last few days of the month and present the bills on or about the first of the following month. Where this method is impracticable owing to the large number of meters, it is customary to divide the city into sections and read one section each day.

Two general methods of recording the readings are in vogue, viz.: by marking the positions of the hands or pointers on a printed fac-simile of the meter dials, and by recording the reading directly in figures.

The advantages claimed for the first method are, that it insures a more close inspection of the dial by the reader, as he is required to record the positions of the hands as nearly similar as possible to their positions on the meters. These readings also furnish a complete record of the movement of the dial hands, which in the case of complaint resulting from loose or misplaced dial hands, are frequently of service in adjusting the matter.

The advantage claimed for the latter method is that it is somewhat more rapid and less cumbersome.

Many different styles of printed forms for recording the dial statements are employed. It is usually customary to provide for each meter a separate card designed for one year's readings. These cards are arranged in the order in which the meters are to be read and the cards for any meters disconnected can thus be removed, and the cards for any meters added can be inserted in their proper positions.

As errors in meter reading frequently result in inaccurate bills which are exasperating to both the consumer and the company, it is always advisable to employ as meter readers only those men who are thoroughly competent and trustworthy. With many companies it is customary to alternate the men in the different sections so that no man reads the same route two consecutive months.

Meter readers are often educated and instructed to make a superficial examination of the meter, wiring, etc., and to report anything defective or irregular.

METER SHOP AND LABORATORY.

Every company having a sufficient number of meters and instruments to justify the necessary expenditure, should have a thoroughly equipped meter shop and laboratory.

The shop should be equipped with a lathe, drill press and all the necessary small tools and should also contain a full supply of all necessary meter parts for the repairing of meters, such as field coils, jewels, dial faces, armatures, magnets, etc. The company is thus enabled to repair its own meters and save the expense and delay incident to the return of the meter to the manufacturer. The shop should be provided with the necessary switchboards, lamp banks, etc., for the testing of all classes of meters in use. For testing alternating-current meters on inductive loads a re-active coil having a capacity of 75 to 100 amperes will be found very convenient, and should be constructed to enable a power factor of 50 to be obtained. The shop should also keep a supply of the necessary tools and appliances used by the testing force, and these it can keep in good condition and thus enable the men to be supplied with the most efficient apparatus only. The shop will be found of the utmost service in educating new men, who can be initiated at once into the repair and testing of all types of meters used by the company, and thus become more conversant with the construction of the meters than would perhaps be otherwise possible.

The benefits of a laboratory to a company are apparent, as it enables the periodic checking of the instruments, standard resistances, etc., used in the testing of integrating meters, thereby insuring the accuracy of the tests. Periodic checking of the switchboard instruments enables the station manager to accurately measure the current and maintain the correct voltage, which he recognizes is of primary importance.

In the laboratory can be repaired and calibrated all types of portable and switchboard instruments.

In some companies all manner of testing and experimental work is conducted by the laboratory, such as the testing of transformers, arc and incandescent lamps, motors, engine and boiler tests, the analysis of oils and fuels, battery tests, the testing of voltages, etc., with portable and recording instruments, photometric work, and making efficiency tests on private plants, etc., this being a partial list of the work.

For meter and instrument work the larger companies have

equipped their laboratories with various original standards with which to periodically check their laboratory standards. The primary standards generally consist of the following apparatus:

A standard potentiometer, such as the Leeds & Northrup, Wolff, Queen, etc., reading to 1.5 volts in steps of .00001 volt.

One or more ratio resistance boxes, for use with the potentiometer, having ranges of 15, 150, 300 and 600 volts.

Two Weston or Carhart-Clark standard cells.

Standard resistances of Reichsanstalt form of 1., .1, .01, .001 and .0001 ohm. These are used in conjunction with the potentiometer, and also as standards for other purposes.

A sensitive galvonometer of the Rowland-D'Arsonval type is necessary for the potentiometer and is also used for other purposes.

A megohm resistance box and other high resistance standards varying from 1000 ohms to 100,000 ohms.

A Rowland electro-dynamometer and shunt box which will measure alternating and direct currents from extremely small quantities to 50 amperes; alternating- and direct-current potentials from .005 to 600 volts; watts from .001 to 25,000. An accurate chronometer or sweep second clock is necessary.

The National Bureau of Standards, Washington, D. C., and the Electrical Testing Laboratories, New York City, are equipped for verifying and standardizing the primary standards.

Secondary standards are used as laboratory working standards, and usually consist of the following:

A Weston laboratory standard direct-current voltmeter having ranges of 3, 15 and 150 volts.

A multiplier of 2 and 4 for the 150-volt range. Additional multipliers of 10 and 20 are sometimes convenient.

A Weston laboratory standard direct-current milli-voltmeter arranged for indicating directly in milli-volts, and also directly in amperes when used with shunts.

A series of shunts, to be used in connection with this milli-voltmeter, having capacities of 1, 2, 5, 10, 20, 50, 100, 300, 600 or 1200 amperes. Also a set of standard shunts of 500, 1000 and 3000 amperes capacity.

A Weston laboratory standard wattmeter of 25 amperes capacity for alternating currents at potentials of 75, 150, 300 and 600 volts.

A portable testing set, current and watt-dynamometer, Kelvin balances, direct-reading ohm-meter, portable galvanometer, curve

tracer, etc., are frequently found in laboratories, and are very useful instruments.

The secondary standards are checked every week with the primary standards, and if found inaccurate are properly calibrated.

The smaller companies use the secondary standards for their primary standards.

The following apparatus and appliances will also be found in a well-equipped laboratory:

Small storage batteries to obtain any voltage up to 600 volts.

Alternating-current potential transformers to give from 25 to 600 volts by combination of turns and coils.

Six or eight cells of storage battery giving 1000 amperes or less at low voltage by different combinations with switches, etc.

A transformer of sufficient capacity to give 400 or 500 amperes at 25 or 30 volts.

Lamp banks for 25 and 110 volts, supplemented with a small rheostat for the finer adjustments.

A sliding, tubular or circular rheostat, made of resistance wire, for potential regulation.

Rheostats for currents not exceeding 5 amperes.

Rheostats made of pencil and plate carbon for currents of 50 amperes or less to be used in connection with the storage battery. For current from 50 to 1000 amperes, lengths of iron wire terminating in mercury cups, and jumpers for different parallel and series combinations, are frequently used.

A switchboard for properly performing the work.

INSTRUCTIONS.

As accuracy in meter work is considered of paramount importance in America, every effort is made to attain this end, which can only be achieved by employing men thoroughly skilled and instructed. To accomplish this, it has become customary for many of the companies to issue detailed rules or instructions covering all branches of the meter work.

The advantages of such rules or instructions have been found to be manifold:

First—The employee cannot disclaim responsibility for work wrongly performed, on the ground of insufficient information received from his superior.

Second—The new employees can be furnished with copies of the instructions, and can therefore instruct themselves with less labor or their own part and that of their superiors.

Third—The writing of the detailed instructions is a self-examination on the part of the writers, and frequently shows them a deficiency of information and knowledge on subjects with which they supposed themselves thoroughly familiar.

Fourth—The periodic revision of the instructions requires close attention to all details, and tends to the elimination of the inferior and the adoption of the more advanced methods.

Fifth—The issuance of these instructions tends to a uniform system of work and methods.

As an example of the instructions the following are extracts from those supplied by The Philadelphia Electric Company:

Routine to Be Followed When Making a Test.

1). Notify the consumer that the meter is to be tested, and exhibit the meter inspector's badge.

2). Check the shop number of the meter with the number entered on the test serial and record.

3). See that the current is on the meter and that the test can be made, as otherwise the time spent in connecting, etc., will be wasted.

4). Enter the time of arriving at the premises.

5). Before the cover is removed the dials should be read by both the tester and assistant, independently, and the results compared, entered on the test page, and verified.

6). Examine the seal very carefully to see that it is intact; also record under "Seal Found" on the test page the number or letter on the seal. The old seal must be defaced.

7). Examine the wiring and fuses to see that they are in good order and that no tampering has been done, that the fuses are of the proper size, that the connections, erection and manner of installation are correct, and enter anything not correct under "Remarks." Note also any departure from the standard method of connection.

8). Remove the cover, being careful that it does not strike any parts of the meter, particularly the dial hands.

9). Connect the instruments and translating device in circuit, being careful that the meter does not measure the potential current of the instruments, and vice versa.

10). Test the meter as found, without in any way cleaning or adjusting it and also determine the number of lamps required to start it. This will show how the meter has been operating.

11). Note under "Level" whether the meter is found level or not. Level it accurately.

12). Examine, adjust, clean and repair the meter as may be necessary. If the meter is damaged to such an extent as to necessitate its removal or repair by a meter mechanic, note this on the test page under "Remarks."

13). Calibrate the meter.

14). Take the statement at the end of the test in the same manner as required in art. 5 and turn the counter back to its original reading, except when the meter is bridged and the consumer uses current during the test.

15). Enter under "Adj." the necessary information, and enter under "Remarks" any information or suggestions which will be of value.

16). Disconnect the instruments, reconnect the meter and see that all connections are secure and properly made.

17). Replace the cover and verify the statement in the same manner as required in rule 5.

18). Seal the meter.

19). See that the meter is in proper operative condition, and that the consumer has current, particular attention being paid to each side of a three-wire circuit.

20). Enter the time of leaving the premises.

21). See that all data, etc., as required on the test record, is entered.

The instructions on meters are usually so written as to constitute a reference and textbook for the meter men. It is customary to consider separately each part of the various makes of meters and to point out the various adjustments necessary in the manufacture of the meter, as well as all the possible troubles which occur in meters in actual service.

The following are extracts from instructions on Thomson integrating wattmeters:

Armature.

The angle between the planes of any section of the armature and its corresponding segment of the commutator is about 90 deg. As variations from the correct angle affect the registration of the meter, the angular position of the armature in relation to the commutator segments must not be changed.

An open circuit in any section will cause the meter to register too low. If the loop is broken from the commutator segment, there will be a jerky movement of the shaft on light loads, and if the meter stops with the brush resting on the segment to which the loop was connected, the meter will not start. If the break is in one of the sections, the meter will readily run on light loads; but will register low throughout its entire range, for the reason that current passes through but one-half of the armature. The break must be repaired or a new armature substituted; both of which usually require the attention of the meter mechanic.

If the insulation of the wire breaks down, thus short-circuiting a large part or an entire section, the meter will register too low.

Brushes.

The tension of both brushes should be the same. If the tension is very light, there may be sparking, which will roughen the commutator and thus affect the accuracy, especially on light loads; if very heavy, the increased friction will similarly affect the accuracy on these loads, in both cases causing the meter to register too low.

The tension of the brushes depends largely upon the local condition, but they should not "jingle" or vibrate when the brush is sprung about three-eighths of an inch from the commutator, then allowed to fly back.

To increase the tension of the brush hold the brush tool parallel with it, and push against the brush at the point where it curves around the brush stud. The brush takes a permanent "set" and usually the tension required can be obtained. The pressure should not be applied to the ends of the fingers, as the brush is apt to be bent and otherwise damaged. No other method than the above should be used for increasing the tension, unless absolutely necessary.

The brush fingers should lie in the same vertical plane. To determine if this is the case, spring the brush from the commutator by pressure near the point of attachment to the brush bracket.

Should the fingers be found in planes inclined to the vertical, grip with the slotted end of the brush tool the end of the finger that is out of alignment and twist it until it "sets" in the vertical plane.

Should the fingers lie in divergent vertical planes, insert the pointed brush tool in the slot of the brush, bring the tool nearly

vertical and push towards the end of the slot. This will spring the fingers and leave them in the same plane. It is necessary to have as much surface contact as possible between the brushes and the commutator. By placing back of the brushes a lamp or piece of white paper the tester will be enabled to determine the amount of contact.

To clean the brushes, a piece of worn (not new) crocus cloth can be placed over or fastened to a thin, flat stick and rubbed lengthwise of the brush, back and forth over the contact surface. A shoestring can also be used in the same manner. If the brush is very badly worn, it is necessary to use a fine file and remove the depression, and then use the crocus cloth as above. Care must be exercised not to damage the commutator during this operation.

No current should be on the potential circuit when adjusting or cleaning the brushes, as the sparking during the operation will damage the commutator and brushes.

It is rarely necessary to clean the brushes if there is no sparking, as it is not advisable to disturb the contact conditions.

Commutator.

It is rarely necessary to clean the commutator unless it is very dirty, blackened, or rough, due to sparking.

If this condition exists, the commutator may be cleaned with a strip of fine crocus cloth, about one-quarter of an inch wide, which has previously been smoothed on a screwdriver or other piece of metal. Never use a piece of new crocus cloth on the commutator.

Ordinarily the commutator can be polished with a shoe string or tape, and it should always be used after the crocus cloth. The method of doing this is to carefully pass the crocus cloth or shoe string around the commutator between the brushes. By alternately pulling on the ends, the shaft will be caused to revolve and the commutator will be polished. Never exert sufficient force to bend the shaft. An air syringe should be used on the commutator to blow out dust particles, etc., as these cause sparking.

The brushes should then be slightly pressed against the commutator by the thumb and finger of the left hand, and the shaft revolved in one direction and the other by means of the right hand. If impossible to use the fingers for this purpose, the brush can be pressed against the commutator by a small flat stick or screwdriver. If the commutator is rough, it is very perceptible on the brushes; and by these alternate revolutions small foreign

particles between the segments of the commutator are dislodged. This also has the effect of making a better bearing between the commutator and the brushes; and it should invariably be the final operation before testing the meter after adjustment, if the commutator has been cleaned.

If two or more segments of the commutator are short-circuited, thereby short-circuiting one or more sections of the armature, the meter will always register too low throughout its entire range.

The short circuit may be caused by small pieces of metal lodged between the segments of the commutator, or lying on the wooden ring below it. The particles between the segments may be dislodged by carefully passing a sharp-pointed stick of hard wood or a piece of fine German silver wire between the segments. The dust on the ring must be thoroughly blown off with the syringe.

To determine whether the commutator is short-circuited, or the armature open-circuited, measure the "drop" across the brushes with a voltmeter.

If two or more segments of the commutator are short-circuited the drop will be variable and always less than the normal drop.

If a section of the armature is open, the drop will be greater than the normal, and the same across any section.

If the loop is disconnected, the drop will be normal until the brush rests on the commutator segment to which the loop was connected, at which point the drop will greatly increase.

Judgment must be exercised to determine between a commutator blackened through sparking and one simply glazed through use, as in the latter condition it will give better results than if newly polished; therefore, the commutator and brushes should be cleaned only when absolutely necessary.

Compensating coil.

The compensating coil, made of fine wire, is placed in one of the field coils, in series with the armature and resistance. Its effect is to balance the friction by exerting a slight torque and its action is especially noticeable on light loads. When the effect of the friction is diminished by vibration, the action of the coil may then be too strong and consequently cause the meter to creep. The coil must then be adjusted.

By moving the coil from the armature its effect is decreased, and by moving it towards the armature its effect is increased.

All meters must be equipped with adjustable compensating coils.

It is desirable to visit the meter after the commutator and brushes have become glazed through use, and adjust the compensating coil for the increased friction.

Counter.

The gears in the counter are of the finest clock work, being all specially cut, and any rough usage may raise burs, which will increase the friction and possibly stop the meter. Dust will also increase the friction, and it is therefore necessary to keep the counter as clean as possible. If it is found to be very dirty, benzine may be used to remove the dirt. The face should always be kept clean.

Special attention should be given to the worm and the worm-wheel to see that they mesh properly and without friction. To determine this move the worm-wheel back and forth with the fingers and the amount of play is immediately apparent. The other gears must also have sufficient play, and this can be determined in the same manner.

The gears should be rigidly fastened to their shafts, and each should be tested separately. At times wheels have been found loose and sometimes bent sufficiently to interfere with the proper working of the meter.

The dial hands or pointers must be rigidly fastened to their shafts and in the proper relative positions, as otherwise the reading is not correct. The hands, if bent, should be straightened.

The counter must always be on the meter when it is calibrated.

When replacing the counter, care should be taken that the worm and worm-wheel are not damaged. The shaft should be revolved after the counter has been replaced in order to determine that the worm and worm-wheel are meshing properly.

Cover.

The cover must be in good condition and the inside should be wiped out and the glass thoroughly cleaned. The cover should be held between the tester and the light in order to determine if any holes exist through which wire, etc., may be inserted to interfere with the working of the meter. See that the dial glass has not been removed, and that the dial hands have not been tampered with. The cover must fit closely around the base of the meter.

Creep.

When the meter is properly installed and the potential (but no load) is on the meter, tapping the base with the fingers will

cause the disc to creep counter clockwise. This is due to the action of the compensating coil, and shows that the meter is properly connected.

If the meter shows a tendency to creep, due to vibration, when the adjustable compensating coil is moved as far as possible from the armature, the creep can be stopped by clamping on the edge of the disc a small staple-shaped piece of iron wire. This wire can be adjusted to stop the creep without affecting the accuracy of the meter. It is only necessary to adjust this clip to stop at the magnet nearest to the edge of the disc, as in such a case a meter can not creep more than one revolution. The utmost care must be exercised in adjusting this clip, and it must, under no conditions extend under the magnet jaws. After placing the clip on the disc re-test the meter on both light and full loads and see that the meter will start on the requisite number of lamps. If the clip is not properly adjusted, it will materially affect the meter on light loads, and may prevent it from starting even on a full load. A clip should not be used unless absolutely necessary.

Field coils.

The appearance of shellaced field coils will show when a meter has been overloaded. A dull color, and sometimes small bubbles, indicate that the shellac has been overheated. The load should be investigated to see that the meter is of sufficient capacity.

Formula.

The formula for calculating the watts registered is:

$$\text{Meter watts} = 3600\ S\ K/T.$$

Where S = Number of revolutions of disc counted.

K = Test constant, or number of watt-hours registered on the dial for each revolution of the disc.

T = Number of seconds indicated by stop watch and corresponding to the number of revolutions of the disc counted.

The number of seconds of each reading should never be less than thirty, and forty to sixty, or even more are frequently preferable.

To calculate the "Percent Accuracy" of the meter, divide the meter watts by the standard watts.

It is preferable to make the calculations with a slide rule, as this method saves time and is less liable to error.

Jewel.

The jewel stone consists of either a small cup of sapphire, a flat diamond with a ring stone or a cup diamond, inserted in the rounded end of a square brass plunger which, in order to give an elastic bearing, is supported on a small spiral compression spring in the jewel screw.

The jewel should be thoroughly cleaned with a pointed stick, covered with chamois skin, and then tested with a sharp pointed needle held normal to its surface; and if found cracked or rough it should be replaced by a new one. Care must be exercised not to bear too heavily with the needle, as the jewel may be scratched during the operation. This refers particularly to the sapphire jewel. If uncertain of the condition of the jewel, alternately test it and a perfect jewel, when, by comparison, any defect is at once apparent. Too many jewels should not be tested with the same needle, as the latter becomes blunted. It is always advisable to put oil on the jewel. The meter should never be moved with the shaft resting on the jewel.

Magnets.

Experience shows that in service the magnets in meters, especially those on direct-current circuits, are often weakened by short circuits, the cause being the excessive magnetic fields developed in the field coils, and the momentary speeding of the disc. The effect is usually a decrease in the strength of the magnets and a resulting increase in the speed of the meter.

The magnets must be cleaned, as foreign particles are apt to become attached to the poles and rub on the disc, thus affecting the accuracy, especially on light loads.

By moving the magnets from the shaft, the speed of the disc is decreased, and by moving them towards the shaft, the speed is increased. These adjustments should be made for large loads only, but they will also affect the calibration of the meter on light loads.

The poles of the magnets should never be nearer the edge of the disc than about one-eighth of an inch, as, when nearer, the magnetic lines pass around the edge of the disc, instead of cutting through it.

When the magnets are so weakened that moving them to within the above distance will not sufficiently retard the speed, the magnets should be changed.

Seal.

Before leaving the meter it must be sealed, and in such a manner that the seal cannot be removed without breaking the seal wires.

Shaft.

The shaft must be straight. To determine if straight, adjust the top bearing to inclose just the end of the shaft, and the latter should then be revolved. If the motion is eccentric, it shows the shaft is bent, and the bend is most likely to occur at the top where the shaft is turned down to fit into the top bearing stud. The shaft must be straightened if bent, as otherwise the worm will not mesh properly with the worm-wheel. The shaft may be bent at the shoulder where it is turned down to fit the disc hub, and this will cause the disc to run untrue. In both cases it is usually necessary to have repairs made by the meter mechanic from the shop.

The worm may be cleaned with a tooth brush or by pressing the sharpened edge of a piece of soft wood against it and revolving the shaft. The stick should be sharpened with the grain, which will allow the worm to cut into it and thus facilitate the removal of the dirt.

Care must be exercised not to bear with sufficient force to bend the shaft.

Shaft End.

The shaft end must be smooth and not worn. It should be examined with a magnifying glass, but where a jewel has been roughened and replaced, it is advisable to put in a new shaft end on the new jewel.

In order to prevent rusting, care should be taken not to handle the shaft end with the fingers.

When removing the shaft end, start it with a solid wrench and remove it with a split-end wrench. While held with the latter, screw it into an old shaft, and it can then be examined without handling.

Never touch the shaft end with anything except a piece of chamois or soft wood, as it is very easily scratched.

Three-wire Meters.

Three-wire 220-voltmeters can be tested as two-wire 110-volt-meters by connecting the field coils in series.

The current should be taken from the same side of the system as that to which the potential circuit is connected, and the constant must be halved when calculating the watts registered.

Top Bearing Stud.

The top bearing stud should be cleaned by inserting a small stick of wood, and then turning it, which will usually wipe out the dirt. Never blow through the hole with the breath, but use the air syringe. When adjusting the height of the shaft the set screw should be loosened, thus leaving the stud free.

The top bearing should be set to inclose about one-half of the reduced section of the shaft, and after this adjustment is made, the shaft should be pushed downward on the jewel to see that the end does not come out of the top bearing.

The hole should be just sufficiently large to allow the shaft to run freely. If too large, the teeth of the worm and the worm-wheel may jam; and if too small, friction will result.

Vibration.

Vibration may cause sparking at the brushes, and the brush tension should then be increased.

Vibration also materially affects the life of the jewel, as the vibration of the shaft on the jewel wears the latter more than the rotation of the moving element.

Excessive wear of the top bearing and of the end of the shaft also results, and these parts should always be thoroughly inspected.

Instruments.

1). All indicating instruments used for testing integrating meters contain light moving parts mounted on shafts, pivoted in jewel bearings. The instruments must, therefore, be handled with the utmost care; as shocks and jars blunt the shaft pivots and damage the jewels, thereby materially affecting the sensitiveness and accuracy of the instruments.

Instruments must never be placed on the floors or hard seats of moving trolley and railroad cars, but should be carried in the hands or on the lap; nor must they be laid on work benches and other supports which are jarred by hammering or otherwise.

If an instrument is allowed to fall it may be completely ruined.

2). Never connect an instrument in circuit unless absolutely certain its range is sufficient for the current or voltage to be meas-

ured. Should its capacity be insufficient, the pointer might be bent, or the instrument burned out in consequence. It is, therefore, best to connect instruments having more than one range so that the first reading will be on the scale having the greatest value; then noting the indication, the leads can be changed so as to bring the reading on the scale which is the best suited for the amount indicated.

An instrument should, if possible, never be connected in circuit so as to cause it to read backwards, as the pointer might be bent in consequence.

3). When in use, instruments should be kept as nearly level as possible, and they should remain in the same place from the start to the finish of the test.

They should be kept clear of motor and other magnetic fields and of large masses of iron, and also from lamp banks and other sources of great heat, all of which are apt to affect the readings.

When instruments are in circuit with their scales in line with each other they should never be nearer than one foot, as the influence of one affects the accuracy of the other and they will not usually indicate correctly if any closer. If the scales are at right angles the instruments may be placed immediately next to one another. If undecided as to whether the current is alternating or direct, hold a permanent magnet to a lighted incandescent lamp connected to the same circuit and if the filament inclines toward the magnet it is direct current. If the filament, however, vibrates so rapidly as to give the appearance of broadening out, it is alternating current.

4). Wire ends and other conductors must not touch the metallic cases, as instruments have sometimes been seriously damaged in consequence.

5). When the pointer is bent or the registration is inaccurate, the instrument should be sent to the laboratory for repairs and calibration. Instruments are tested weekly, but if any uncertainty as to their accuracy exists, always send the instruments to the laboratory to be tested.

Direct-current Instruments.

6). The instruments used for testing integrating meters on direct-current circuits are voltmeters, ammeters and milli-voltmeters with shunts.

7). The Weston instruments are used by this company, and as these instruments contain permanent magnets, they must not be brought within the range of the strong magnetic fields of dynamos and motors.

8). The coil carrying the pointer is wound on a metal form which moves in a strong magnetic field, and consequently its movements are checked or dampened. These instruments are, therefore, "dead beat" and the pointer comes to rest almost instantly. Ordinarily the pointer will not strike the case with sufficient force to be bent, but short circuits and overloads may effect this result.

9). Good contact must be made between the leads and the binding posts. The leads must be kept off the ground, as otherwise short circuits may result. This applies particularly in districts where the neutral is grounded.

Voltmeters.

10). Voltmeters used on direct-current circuits usually have two scales—one, zero to 150, and the other, zero to 300 volts. As these instruments are most accurately calibrated at about 110 and 220 volts on the two scales respectively, it is, therefore, advisable to use the scale best suited to the voltage to be measured.

11). The voltmeters should be connected on the service side of the integrating meter, when testing meters on light loads, and to the points to which the potential meter leads are connected when testing on large loads. This is desirable on account of the drop in the field coils.

Ammeters.

12). It is ordinarily not advisable to use ammeters for testing, owing to the difficulty of reading small currents on instruments of sufficient capacity to test 25-ampere meters and larger. There is also often a temperature error when the instrument remains too long in circuit.

13). When an ammeter is used, it must not be so connected as to measure the current consumed in the potential circuit of the integrating meter.

Milli-Voltmeters with Shunts.

14). A milli-voltmeter calibrated for use with a shunt usually does not measure true milli-volts. The instrument most used by

us has 150 small divisions on the scale, and the shunt box contains three shunts marked 1.5, 15 and 75 amperes. Therefore, the divisions on the scale for each ampere are 100, 10 and 2 respectively. The main leads are connected in the binding posts on the current side of the shunt box, and the special instrument leads to the corresponding binding posts on the instrument side. These leads are furnished with, and have the same number as, the instrument; and under no conditions must any other leads be used, or the lengths of the leads be changed.

15). When changing connections or load, etc., disconnect from the instrument the lead not attached to binding post marked + on the shunt, and place this end under any one of the unused instrument binding posts on the shunt. A short circuit or overload, which will not affect the shunt when the instrument is disconnected, may bend the pointer and burn out the small coils in both the shunt box and the instrument when the latter is connected.

16). The instrument leads should be covered with rubber tubing and kept clear of the ground. At times, reverse readings, due to leakage, have resulted from lack of this precaution.

17). In districts where the neutral is grounded, it is imperative, where possible, to have the neutral wire connected to the shunt, as, under these conditions, no short circuit would result if the terminal of the instrument lead makes contact with the ground.

18). Many of the milli-voltmeters are supplied with additional shunt boxes for currents of 150, 300 and 600 amperes.

Alternating-current Instruments.

19). Instruments used for testing integrating meters on alternating-current circuits are voltmeters, ammeters and wattmeters.

20). These instruments do not contain permanent magnets; and while they may be used on direct current, it is necessary, in the latter case, to make reverse readings and to take the mean. This is inconvenient, and when employed in actual service, often inaccurate; consequently, these instruments should not be used on direct-current circuits.

21). Instruments with permanent magnets, besides being unsuitable, may be ruined if connected to an alternating-current circuit. They must, therefore, never be connected on such circuits.

22). Alternating-current instruments are not permanently injured if brought within the fields of motors and dynamos. They are, however, when in use, more susceptible to the influence of

magnetic fields than the direct-current instruments; and special care must be exercised to keep them away from such fields and any masses of iron.

23). It is always advisable to twist the current leads to the alternating-current instruments, as otherwise, the unneutralized field from the leads will materially affect the accuracy of the instrument.

24). These instruments are generally not "dead beat" and consequently the pointer must be carefully released and its motion checked by the contact key, as otherwise, the pointer will be bent and the jewels injured. The contact key should only be depressed when a reading is to be taken.

25). These instruments have heavier moving parts and less control than the direct-current instruments and are therefore more liable to derangement. The pointer will more frequently show a zero error. Always allow the pointer to return to zero when the instruments are not in use, as otherwise the springs, which are very delicate, take a permanent set, thus affecting the readings, and causing the pointer to remain off zero.

26). Never wipe off the glass or rubber top just before taking a reading, as this will electrify it and render the reading incorrect. When the pointer will not return to zero, due to a static charge, breathe on the glass, and by this means the charge will be dissipated—allowing the pointer to return to zero.

27). The instrument will be affected if its parts are statically charged or if the integrating meter which is being tested is charged. Sometimes it is necessary to ground the meter or one of the main wires, and this is frequently the case when testing primary meters. The grounding should always be done through a 1-ampere fuse wire at least 6 ins. long, and preferably inclosed in tape, as in case the other side of the circuit is grounded, a "dead" short circuit would result.

Alternating-current Voltmeters.

28). The instruments most suitable for our work have scales with two ranges, zero to 150 and zero to 300 volts. The portion of the 150-volt scale most generally used is divided so that the value of each small division is one volt. The small divisions on the 300-volt scale have a value of 2 volts each.

The voltmeter must not be left in circuit continuously, but the

circuit must be broken after each reading by means of the contact key.

29). A thermometer is placed in the instrument, and the pointer of the temperature regulator should be set at the figure which corresponds most closely to the indication of the thermometer.

30). For pressures exceeding 300 volts, multipliers for the larger scale of the instrument are supplied.

31). Multipliers should be clean and dry, as otherwise they may burn out, damage the instrument, or cause it to read incorrectly. If brought from a cold into a hot atmosphere, they should not be used for ten or fifteen minutes, in order to allow the multiplier to assume the temperature of the surrounding air, and the condensation of moisture on the resistance to evaporate.

32). The voltmeter must be connected on the service side of the integrating meter, when testing meters on light loads, and to the points to which the meter potential leads are connected when testing on large loads. This is necessary in order that the voltmeter will receive the same voltage as does the meter.

33). When a voltmeter is connected to a motor circuit, the contact key must be released before the motor is shut down, as the back e.m.f. may seriously damage the instrument.

Alternating-current Ammeters.

34). There are no thoroughly reliable portable alternating-current ammeters for accurate testing, and for this reason they are seldom employed for this work. When they are used, they should be calibrated just before the test is made. Their principal use is for determining the power factor.

Wattmeters.

35). The wattmeter is a combination of a voltmeter and an ammeter, so designed that it will measure true watts and not necessarily the volts multiplied by the amperes. This is the only instrument which will correctly measure the energy of inductive loads; and the quotient of the true watts divided by the volt-amperes is the power factor.

37). The Weston wattmeters are made in the following sizes: No. 1, 2 amperes; No. 2, 10 amperes; No. 3, 25 amperes; No. 4, 50 amperes; No. 5, 100 amperes; No. 6, 200 amperes.

38). Wattmeters of the above sizes are kept at the laboratory, and at least one of each of these sizes is provided with a multiplier

of 2 and 4; and the instruments can be used on circuits of 220 and 500 volts.

39). As the capacity in amperes and volts is limited, care must be exercised that neither of the limits is exceeded, as otherwise the instruments may be burned out. When testing on inductive loads, the watts give but little indication of the current or voltage.

If there is any uncertainty, a voltmeter and ammeter should be used in conjunction with the wattmeter.

40). The potential circuit binding posts "+ or —" must be connected to the same lead which is connected to the binding posts of the current coils. The special use of this post is to determine the wattage of a bank of lamps, or other translating device. The potential circuit is then connected directly at the lamps, and, consequently, receives the same voltage as the lamps, any drop in the main wires being eliminated from the measurement.

It will be seen that the current for the potential circuit when thus connected passes through the current coils, and therefore should be indicated by the instrument. To eliminate this, the "+ or —" potential binding post is connected to a compensating coil with poles opposed to the current coils, and the instrument therefore does not indicate the current used in its potential circuit.

If a lead of opposite polarity to that connected to the current coils is connected to the "+ or —" potential post, there would be the maximum difference of potential between the field and compensating coils, which usually burns out the latter.

41). The independent post mark "Ind." should be connected to the same side of the circuit to which the current coils of the instrument are connected. When measuring small loads the potential leads should be connected to the lines on the service side of the meter, as by this arrangement neither the meter nor the instrument measures the current consumed in the potential circuit of the other.

42). When testing on large loads the potential leads should be connected at the points where the potential wires of the integrating meter are connected. The integrating meter will then measure the current in the potential circuit of the instrument, but as the amount is only about two watts it may be neglected. Whenever possible, the instrument should be so connected that neither the meter nor the instrument measures the potential circuit of the other.

43). If the instrument indicates backwards, when connected as stated, reverse the connections to the current coils.

44). When a multiplier is used it must be connected in series with the wire attached to the 150-volt potential post, and never with the "Ind." or + or — potential post, as the instrument will invariably burn out.

45). When wattmeters with "Ind." potential posts are used to measure the energy consumed by inductive translating devices, the instrument should be connected so that the "Ind." potential post can be used. When the + or — post is used the instrument may not indicate correctly on account of the phase relations.

Appendix.— Printed Information on Electric Meters.

Lyman C. Reed. "American Meter Practice." 1903. McGraw Publishing Co.

International Correspondence School Textbook, "Electric Lighting and Street Railways." Vol. 2, Sec. 14, pages 79 to 102 inc.

J. A. Fleming. "Hand Book for Electrical Laboratory and Testing Room." D. Van Nostrand Co. Pages 1 to 109 inc.

G. D. Aspinall Parr. "Electrical Engineering Measuring Instruments." D. Van Nostrand Co. Small portions devoted to meters throughout the book.

Francis B. Crocker. "Electric Lighting." 1901. D. Van Nostrand Co. .Pages 432 to 450.inc.

Horatio A. Foster. "Electrical Engineers' Hand Book." 1903. D. Van Nostrand Co. Pages 615 to 635 inc.

Papers read before the Conventions of the various Electrical Associations.

Trade literature and articles in the electrical journals.

Copies of Patent Specifications.

Discussion.

Chairman Lieb: We have time enough for a few remarks if any of the gentlemen here present feel they wish to make any. I will say for the benefit of our good friends from abroad that this is a Congress address, almost a book, which gives in very great detail the meter practice as developed by one of the larger American electricity supply companies and will undoubtedly be found interesting to them in making comparisons with their own practice.

Mr. J. R. Dick: The first thing that strikes the European engineer in looking over this paper is the fact that the only type of meter referred to is the watt-hour type. The development of metering in European countries has been in rather a different direction. Now, I want to suggest to the American engineers, who adhere to the watt-hour type that there ought not to be any preference given to that type over the ampere-hour type, because theoretically and in actual results you are obliged to keep the voltage variation within close limits. If your regulation approximates to 1 or 2 per cent, there is no objection to the latter type, and it would be fair to both the customer and the supply undertaking. The last part of the paper deals with troubles, and the gist of it is how to minimize these troubles of considerable magnitude which occur in all mechanical meters. I cannot help, Mr. Chairman, having a preference for a certain class of meter — I make both mechanical and electrolytic — but from many years' study of the subject I am convinced that the electrolytic meter holds a prominent place. You have no trouble from friction, you have the same accuracy of registration after five years, and you need not consider in the least whether your meter is working near its declared full load, or within one-tenth of it, because the accuracy record is the same. Thus you have the further enormous advantage, that you do not need to store a large variety of sizes, for you can make a single design to be operated at any working load, from one-tenth up to its nominal full load, and always with the same sensitiveness. Then, again, you get rid of commutator troubles, and all varieties of friction owing to the action of the meter being molecular instead of mechanical motion.

Mr. W. C. L. Eglin: I think, as the Chairman has said, this is a paper which can be studied by the central-station man who wishes to study the defects which may arise in individual meters. In reference to the point made by Mr. Dick as to the electrolytic and mechanically-operated meters, of course we went through an experience with a dozen electrolytic and chemical meters in this country. One of the necessities in a satisfactory meter is that you must give the consumer something he can read. The electrolytic meter has been improved tremendously within the last few years, but our practice was changed at a time when the consumer demanded reading his own meter. The objection to the ampere-hour meter is two-fold: It does not give an absolutely accurate record of the consumption of energy, and in law, under ordinary conditions, we lose a case if we admit that the meter may be 2 or 3 per cent fast or slow. It is not exactly what you sold to the consumer — it may be 2 or 3 or 4 per cent, one way or the other. In alternating-current supply it is decidedly disadvantageous, because the ampere-hour meter is very inaccurate on inductive loads, so that for these reasons the United States adopted as standard the watt-hour meter and the watt-hour is the standard unit in the United States, and not the ampere-hour. It was the most accurate unit and what we were attempting to obtain was the greatest accuracy in our meter work.

Chairman Lieb: I will say for Mr. Dick's information that we have no such thing in this country as declared pressure, which is really the

element which is furnished, and which is lacking in the ampere-hour meter. That does not mean that we do not maintain a reasonably accurate pressure, but we have no such thing as a declared pressure — either declared by the State, or by a municipality.

Mr. DICK: Do I understand then that your Legislature prescribes the use of a wattmeter?

CHAIRMAN LIEB: No, sir; but there is to-day no other meter, practically, in the market in the United States for measuring direct current than the recording wattmeter. That is the state of the case. If there is no further discussion, we will now consider the discussion closed.

I will say that we have two papers which have not been brought before the Section, one by Mr. V. Poulsen on "Production of Continuous Electric Oscillations." We will consider this paper as read by title.

SYSTEM FOR PRODUCING CONTINUOUS ELECTRIC OSCILLATIONS.

BY V. POULSEN.

It is known that Mr. Duddell, in the year 1900, discovered that a direct-current arc, shunted with a condenser in series with a self-induction, as in Fig. 1, will, under certain conditions, give out a musical note, and transform part of the direct current into alternating current with constant amplitude; the energy dissipated in the condenser circuit in ohmic loss being supplied from the direct current. Duddell found, however, that the arc is only "musical" when the following conditions are satisfied:

If dV is a small change in the p.d. between the terminals of the arc, and dI the corresponding change in the current through

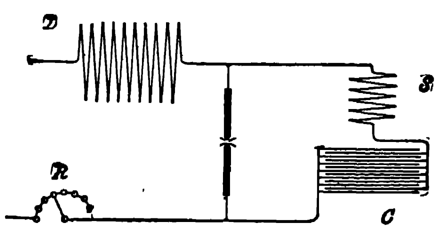


FIG. 1.

the arc, then dV/dI must be 1), negative; 2), numerically greater than the resistance of the condenser circuit; and 3), numerically less than the resistance of the direct-current circuit in series with the arc. These conditions are fulfilled if the arc is formed between solid carbons.

This simple way of producing alternating currents of even high frequency seemed, justly, to be the nearly ideal principle for the securing a system for producing continuous electric oscillations — i. e., alternating currents of very high frequency.

When experimenting some years ago with the musical arc, I made an observation which, followed by occasional experiments, led me to the construction of a generator for producing continuous electric

oscillations. A short, general description of some of my experiments and arrangements will here be given.

Fig. 1 shows the diagram of an ordinary musical arc. *D* is a choking coil, *S* is the self-induction, and *C* the capacity in the shunt circuit. *R* is a regulating resistance inserted in the direct-current circuit.

In view of my first experiment, the carbons were placed horizontally and coaxially, as shown in Fig. 2. In this way an ordinary spirit-lamp could be held under the arc in such a manner that the latter and the adjacent parts of the electrodes were quite surrounded by the spirit-vapor. The ammeter *A* was placed in the direct-current

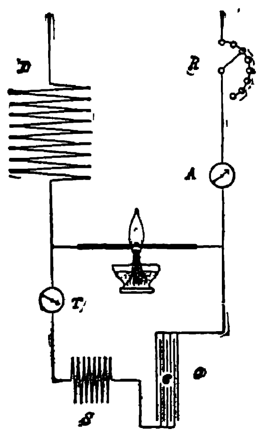


FIG. 2.

circuit, and the hot-wire ammeter *T*, in the condenser circuit. The direct current was taken from an ordinary 220-volt lighting circuit.

When the musical arc was placed in spirit-vapor in the abovementioned manner, then the note abated in pitch, while at the same time *T* showed a considerable increase in the alternating current, and the direct current dimished. Furthermore, the emission of light of the arc diminished, as is usual with hydrogen and hydrogen compounds. As with the atmospheric arc, the note also increased in pitch in the alcoholic arc when the direct current was increased. A different length of arc was required in spirit-vapor than in air to give a maximum current in the condenser circuit.

Table I contains the data of two series of experiments; one in which the distance between the electrodes is adapted to spirit-vapor and another in which it is adapted to air.

The large choking coil D was without iron and had an inductance of 0.19 henry. The self-induction S without iron was 5.6×10^{-4} henrys and the capacity of the condenser[1] was about 2.5 microfarads.

Resistance of R + D in ohms.	Direct-current p d between the electrodes.	Direct-current in amperes.	Alternating current in amperes.	Distance between the electrodes in mm	The arc being in:
54	101	3.2	6 9	Abt 2 0	Spirit-vapor.
54	47	3 2	2 4	" 2 0	Air
36	83	3.8	9 0	" 2 7	Spirit-vapor.
36	47	4 8	2 4	" 2 7	Air.
54	31	3.5	3.1	" 1 2	Air
54	31	3.5	5 8	" 1 2	Spirit-vapor.
36	29	5.3	4 6	" 1.0	Air
36	29	5.3	6.0	" 1.0	Spirit-vapor.

In the first series of experiments V/I was greater for the spirit arc than for the atmospheric arc. In the second series the pitch of the note was very nearly the same in air and in spirit-vapor; and the inserted resistances and direct currents being the same, the energy in the condenser circuit is proportional to the square of the current.

The inserted resistances, as also S and C, were chosen arbitrarily. The superiority of the spirit-vapor became, with relation to the air, greater than in the above-mentioned experiments, when the ratio S/C was taken greater. The same effect as spirit-vapor was given by hydrogen, ordinary coal-gas, and ammonia-gas. As even water-vapor gave an effect similar to that of the hydrocarbons at low frequencies, the effect seemed to be produced by the hydrogen. That the effect was not due to the streaming of the gas became evident through experiments in a closed vessel.

When the image of the hydrogenic arc was projected upon a screen, the condenser circuit not being closed, the arc was observed as a greenish-blue spot with a very faint trace of a purple-colored core. As soon as the arc was made "musical" by closing the condenser circuit, it became thick, the purple-colored core becoming then very marked. When there a copper anode and a carbon cathode were used instead of two carbons, the core was particularly beautiful.

As I aimed at obtaining frequencies as high as possible, and as

1. The insulation of the condenser was not good.

the superiority of the hydrogenic arc became more evident when the ratio S/C was made greater, as above mentioned, I laid special stress on dimishing C, which was reduced with good result down to 1×10^{-4} microfarads.

The hydrogenic arc gave out "musical" notes, or rather electric "notes," of several hundred thousand oscillations per second, and even though of less intensity, some millions of oscillations per second. The excellent resonance effect that can be obtained by these oscillations indicate their continuity, and in the rotating mirror it is seen that the oscillations actually are continuous.

At high frequency, alcohol did not prove to be as good as hydrogen, coal-gas, or ether. Furthermore, it was shown to be necessary to draw out the arc to a certain length in starting the oscillations. When the oscillations are started, the length, as a rule, can be lessened a little, without the oscillations ceasing. If the length of the arc is increased, then the oscillations continue, and cease only when the distance between the electrodes has become so great that the arc is extinguished.

When the arc oscillates in a gas flame, this latter assumes a special form. If the ratio S/C is small, the appearance of the flame and arc is very curious, the gas, or particles in the gas, being projected from the arc with a blowing sound. If the ratio S/C is very small or very great, the arc cannot oscillate.

On some few occasions I got, when S/C was great, a momentary p.d. between the coatings of the Leyden jar which represented C so great that the edge became luminous and the odor of ozone was present. As this was not repeated later on, I placed my oscillating arc in a transverse magnetic field, under otherwise the same conditions, in order to see whether this would be of avail.

The increase in the effect was very striking. From the Leyden jar was heard and seen a splendid luminous ring of small discharges from the edge of the inner coating. The heat caused thereby became so great that the tinfoil melted at the edge and the Leyden jar cracked in a circle. When, instead of a permanent magnet, I used an electromagnet, inserted in the direct-current circuit (see Fig. 3), then the arc became more stable and showed, with the electrodes suitably formed, and with even a magnetic field of 1×10^4 to $1{:}5 \times 10^4$ gausses, no tendency to extinguishment.

In the magnetic field the resistance of the arc, or rather the ratio V/I, is very great, and the more so the greater is S/C. When the electrodes are drawn back from each other in the magnetic field, the

direct current decreases until that length of the arc is attained at which the oscillations begin; the direct current then increases again somewhat, that is, the oscillations lessen the resistance of the arc.

When the hydrogenic arc is placed in a magnetic field as mentioned, S/C can be chosen much greater than otherwise. On the other hand, the magnetic field will do more harm than good when S/C is small.

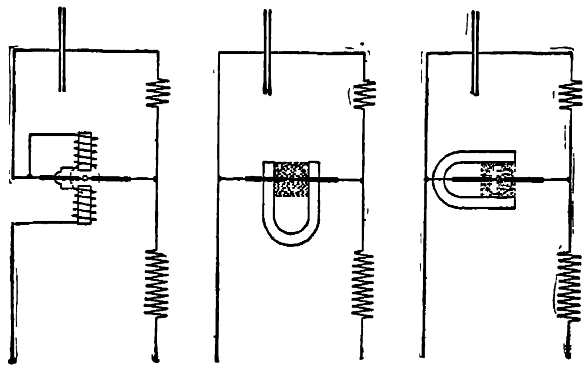


FIG. 3.

The atmospheric musical arc cannot be established with a value of S/C that makes the magnetic field applicable to the hydrogenic arc, and the magnetic field is, moreover, quite inapplicable to the atmospheric musical arc. A magnetic field parallel to the hydrogenic arc shows about the same effect as a transverse field.

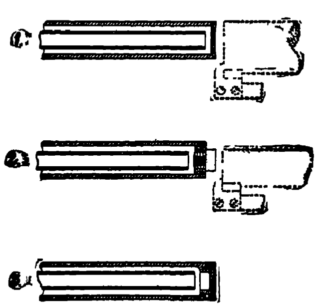


FIG. 4.

As electrodes I have used, besides carbon to carbon, different metals, for example, with good effect + copper cooled by running water, to — carbon. Some forms of water-cooled electrodes are shown in Fig. 4.

The wear is surprisingly small. Silver, copper, and mercury are about equally good anode metals for the oscillating arc. + copper to — copper proved on some occasions to be of very great effect; but this combination in general gives rise to discontinuities in the oscillations.

Where there is wanted an arrangement that can stand and take care of itself for a longer time, it is necessary to remove the carbon deposit from the electrodes in order to keep the length of the arc and the shape of the electrodes unaltered. This can be done by scraping the rotating electrodes with knives of hard and fireproof material, such as talc or self-hardening steel.

If the electrodes are placed horizontally in a transverse magnetic field, then the arrangement ought to be such that the arc is forced upward, at any rate, not downward. An arrangement sufficiently good for many experiments is that shown in Fig. 5. Here a cooled copper anode is fixed opposite to a rotating carbon cathode (speed

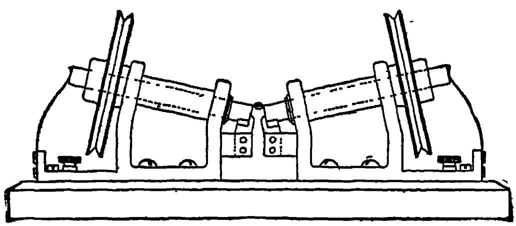


FIG. 4a.

at the periphery 2 to 5 mm.p.s.) in an ether or gas flame (not a Bunsen burner). The magnetizing coils can replace the choking coil. In order to avoid soot deposits, one may inclose the arc in a case, preferably cooled by water, and let the gas stream out from it, for instance, to a Bunsen burner; if the gas has no outlet, then the effect is lessened gradually, especially, when a strong current is used, the composition of the gas being altered at the same time.

If an ordinary Leyden jar is used instead of an air or oil condenser, the jar becomes very warm, if the tinfoil does not closely adhere to the glass.

In case the coatings closely adhere to the glass everywhere, then the jar can be used, if vaseline or a similar insulating substance is spread over the coatings on the inside and on the outside, so that their edges are well covered by the oil.

In some recent experiments I obtained, with a frequency of about 5×10^4, in the condenser circuit, about 1560 watts, the arc at the

same time taking from the direct-current circuit about 3170 watts; the efficiency was thus about 50 per cent. With 1140 watts in the condenser circuit, the direct watts were 2700, the efficiency thus being 42 per cent. With 464 watts in the condenser circuit, the direct watts were 1070 and the efficiency thus 43 per cent. The frequency being about 1.6×10^5, I had in the condenser circuit 800 watts, the direct watts being 2800; the efficiency thus only proved to be 29 per cent. The supply voltage during all these experiments was 440 volts.

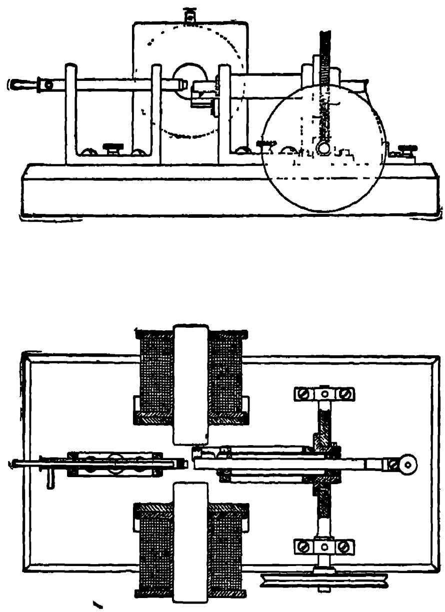


FIG. 5.

The supply voltage being 220 volts, I obtained with a frequency of about 5×10^4 in the condenser circuit, 358 watts, the direct watts being 718; this gives an efficiency of 50 per cent. With a frequency of only 3000 to 4000 periods, I had in the condenser circuit 282 watts, the direct watts being 656 and the efficiency thus 43 per cent.

In regard to all the above-mentioned experiments no preparations were made to obtain the greatest efficiency or effect. For instance, the arc was placed in a water-cooled vessel, without outlet for the gas, this being necessary to determine the energy; this lessened the intensity of the oscillations, as mentioned above, while at the same time the composition of the gas was altered. At a low frequency

the alteration of the gas does not impair the intensity so much; on the other hand, the insulation was very bad in the condenser used for the frequencies of 3000 to 4000.

That my system for producing continuous electric oscillations admits of handling a good deal of energy at even very high frequency has been proved by different experiments in connection with the ordinary lighting circuit of 220 volts. A resonating coil gave, when it was connected by the Seibt arrangement to an oscillating circuit with the ratio henrys 1 microfarads $= 4.8$, a noiseless, very warm flame of a length of 12 cm. The frequency was 1.2×10^5. If the flame is made short, it can distinctly be seen in the rotating mirror to be continuously oscillating. A large Röntgen tube was placed between the terminals of a coil inductively coupled with an oscillation circuit with a frequency of about 2×10^5, and in a short time the cathode and the anti-cathode melted.

An ordinary 200-volt incandescent lamp glowed when placed in series with two persons, one of whom was connected with an oscillating circuit, the ratio S/C being about 1. A Seibt resonating coil with the frequency 8.4×10^5 gave a flame of a length of about 1 cm; an inductively coupled coil with the frequency 1.1×10^6 gave the same length.

If one surrounds the secondary coil of an ordinary spark coil with windings of thick-copper wire and places these windings in series with a capacity of some microfarads shunting a hydrogenic arc, a very loudly singing flame of a length of 10 to 12 cm or more is obtained. A Röntgen tube with this arrangement gives a very strong radiation.

When the ratio S/C is great — about 15 —, there is a considerable p.d. directly between the condenser plates. With a frequency of 50,000 to 150,000 there are thick sparks of 2 to 5 cm long when the self-induction is shunted with a spark-gap.

Fig. 6 shows a diagram with two oscillating circuits of the same frequency; by means of such an arrangement oscillating flames of about the double voltage can be obtained.

I noticed that the musical arc placed in nitrogen gave rise to larger alternating currents than in air; at the same time I noticed that the atmospheric arc gave a larger alternating current before the carbons become quite hot. From this I conclude that the musical arc, considered as an electric transformer, is handicapped by the oxygen and that this circumstance is connected with the combustion.

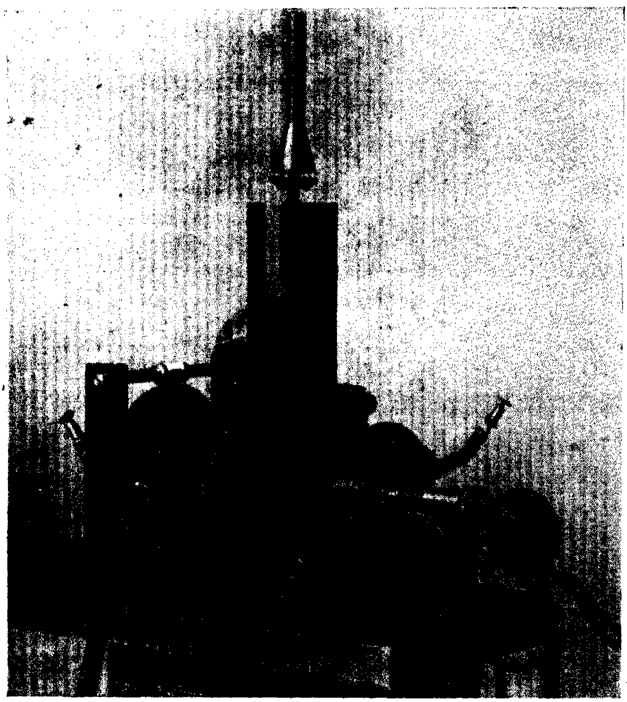


Fig. 7.

I could not obtain with the nitrogenic arc as high frequencies, combined with high currents, as with the hydrogen arc.

Since the oxydation of the electrode material seems to reduce the alternating currents, as above mentioned, it is natural to conclude that the superiority of the hydrogen is partly due to its great affinity for oxygen, which, even in small quantities, must be supposed to affect the oscillations adversely. Without going into a more

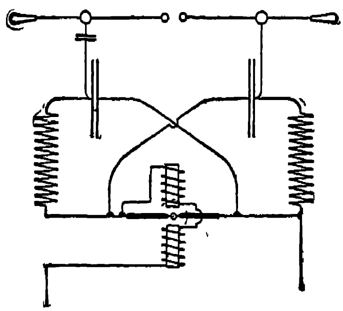


FIG. 6.

detailed explanation of the influence of the hydrogen on the musical arc, I will only mention the peculiar position of hydrogen among the elements with respect to velocity of the ions.

On the basis of the experiments I have made with the "oscillating arc," I believe that it can in future be used as an electric generator for syntonic wireless telegraphy and telephony. Without mentioning other technical uses for which, I believe, it is fitted, I may, finally, express the hope that it will be of a value to physicists and electricians comparable to that of the Rühmkorff coil in the past.

CHAIRMAN LIEB: We will now take up the paper by Mr. H. F. Parshall on "The Yorkshire & Lancashire Electric Power Company." I shall be very glad if one of the members of the Institution of Electrical Engineers will abstract this paper very briefly. It seems to be a striking and interesting paper, giving a history of the work and the Act of Parliament covering the rights given to the company. As the paper is in print and members have a copy of it, those who are interested in it can read it.

THE YORKSHIRE & LANCASHIRE ELECTRIC POWER COMPANIES.

BY H. F. PARSHALL.

The author, who is the engineer to these undertakings, describes them as illustrations of a numerous class of general supply companies, authorized by Parliament to generate, distribute and sell power over wide areas in England and Scotland.

For the edification of those not acquainted with British Parliamentary clauses I quote the following as the substance of the special powers granted by the Act of 1901 to the Yorkshire Power Co.:—

The Company shall be established for the purpose of constructing, erecting, laying down, maintaining, working and using electric generating stations and works and producing, generating, using and supplying electrical energy or power and generally carrying out the powers and purposes of this Act and the powers of the Company shall include the acquisition, construction, erection, maintenance, enlargement, alteration, working and use, or discontinuance, sale, letting and disposal of all such lands, easements, buildings, collieries, works, machinery, plant, stock, electric current, wires, lamps, motor fittings, meters, and of apparatus, material, matter, and things, and the exercise of such powers and doing of such works and supply of such material and product, matter and things as may be necessary or convenient in, for, or in connection with or arise or be used in the production, generation, use, storage, regulation, transforming, transmittal, measurements, distribution and supply of such energy or power or the fitting up and the repairing of any such articles and things or for providing or working, material, matter and things for those purposes or any of them or otherwise carrying on the undertaking.

The following is the substance of the special restrictions:—

The Company shall not either directly or indirectly supply energy for any purpose to or within any such city or borough nor execute any works within any such city or borough for the purpose of supplying energy to consumers within such city or borough except with the consent in writing of the Corporation under their corporate seal.

The maximum rates of charging were fixed by Parliament and are as follows:—

SECTION I.

A. To authorized undertakers —

1. A standard charge for service at the rate of ten shillings per electrical horse power for the supply of which the Company is required to make provisions; and
2. In addition a charge for current determined by meter after transforming as follows:
   (A) For the first 5,000 units consumed in any quarter at the rate of 3d. per unit;
   (B) For all units consumed between 5,000 and 10,000 in any quarter at the rate of 2¾d. per unit;
   (C) For all units consumed between 10,000 and 20,000 in any quarter at the rate of 2½d. per unit;
   (D) For all units consumed between 20,000 and 50,000 in any quarter at the rate of 2d. per unit;
   (E) For all units consumed between 50,000 and 100,000 in any quarter at the rate of 1½d. per unit;
   (F) For all units consumed between 100,000 and 200,000 in any quarter at the rate of 1d. per unit;
   (G) Amounts over 200,000 units consumed in any quarter at the rate of ¾d. per unit; and

B. To persons other than authorized undertakers twenty per cent in excess of the above rates.

SECTION II.

A. To authorized undertakers:—

(1) For any quantity not exceeding the equivalent of one hundred hours of supply at the maximum power which has been demanded by him at the rate of threepence per unit.
(2) For any further quantity exceeding the equivalent of one hundred and not exceeding two hundred hours of supply at such maximum power at the rate of twopence per unit.
(3) For any further supply exceeding the equivalent of two hundred hours of supply at such maximum power at the rate of one penny per unit.

B. To persons other than authorized undertakers twenty per cent. in excess of the above rates.

Turning next to the Lancashire Electric Power 1902 Act the substance of the general powers are the same as in the Yorkshire but the restrictions are much more onerous since it is stipulated that:—

The powers by this Act granted shall be exercised only for the purpose of supplying energy to some general supply district or to or on behalf of some local authority authorized by License Order or Special Act to supply energy within the area of supply or to some Company so authorized, and the Company shall not except for the purpose of obtaining convenient access to some such district or to the area of supply of some such authority or Company exercise under the authority of the Act any of the powers of the principal Act in reference to any street.

The maximum prices which the Company are entitled to charge are fixed by Parliament and are as follows:—

SECTION I.

Where the Company charges by the actual amount of energy supplied they shall be entitled to charge at the following rates per quarter:—

(A) For any quantity not exceeding the equivalent of one hundred hours of supply at the maximum power which has been demanded at the rate of fourpence per unit;

(B) For any further quantity exceeding the equivalent of one hundred and not exceeding two hundred hours of supply at such maximum power at the rate of twopence per unit;

(C) For any further quantity exceeding the equivalent of two hundred hours of supply at such maximum power at the rate of one penny per unit.

SECTION II.

Where the Company charges by the electrical quantity contained in the supply given they shall be entitled to charge according to the rates set forth in Section I of this Schedule the amount of energy supplied being taken to be the product of such electrical quantity and the declared pressure of the ends of the electric lines situate upon the premises of the local authority and belonging to them at which the supply of energy is delivered from the electric line connecting with the premises of the Company that is to say such a constant pressure at those terminals as may be declared by the Company under any regulations made by them.

It is unnecessary to make further comment as to the various provisions in these two Acts than to state the work shall be carried out with due regard to public safety and convenience and in accordance with the various Acts of Parliament relative to such undertakings.

The following statement gives the main characteristics of these two districts.

First as regards the Lancashire Company, the area of supply covers 1200 square miles. This area is probably the most important industrial and manufacturing centre in the United Kingdom. It has a population of upwards of 2,250,000, and contains about 18,500 factories and workshops, and about 700 quarries, blast furnaces, and collieries, employing, it is estimated, 1,500,000 horse-power.

There are within the area 122 local authorities, and of these only 28 have established, or commenced the construction of, works for the supply of electricity. They supply but a small fraction of the population, mainly for lighting purposes, and the supply of electricity for power in this vast industrial area has not yet been seriously commenced. Although out of the remaining 94 of these local authorities 28 have obtained Provisional Orders, they have not yet exercised their powers, and many of these are already in negotiation with the Company for a supply of electricity in bulk. Fig. 1 is a map of the areas of supply showing the boundaries of the local authority districts and location of generating stations.

Next as regards the Yorkshire Company the area of supply covers 1800 square miles. Population, 2,000,000. Number of local authorities 156, made up of 5 County Boroughs, 13 Non-County Boroughs, 116 Urban District Councils, 22 Rural District Councils. Number of Collieries 406. Estimate of total power used 1,500,000 to 2,000,000 horse-power. Of the quarries, 40 come under the Mines Act, there are probably another 100 who do not. Number of fac-

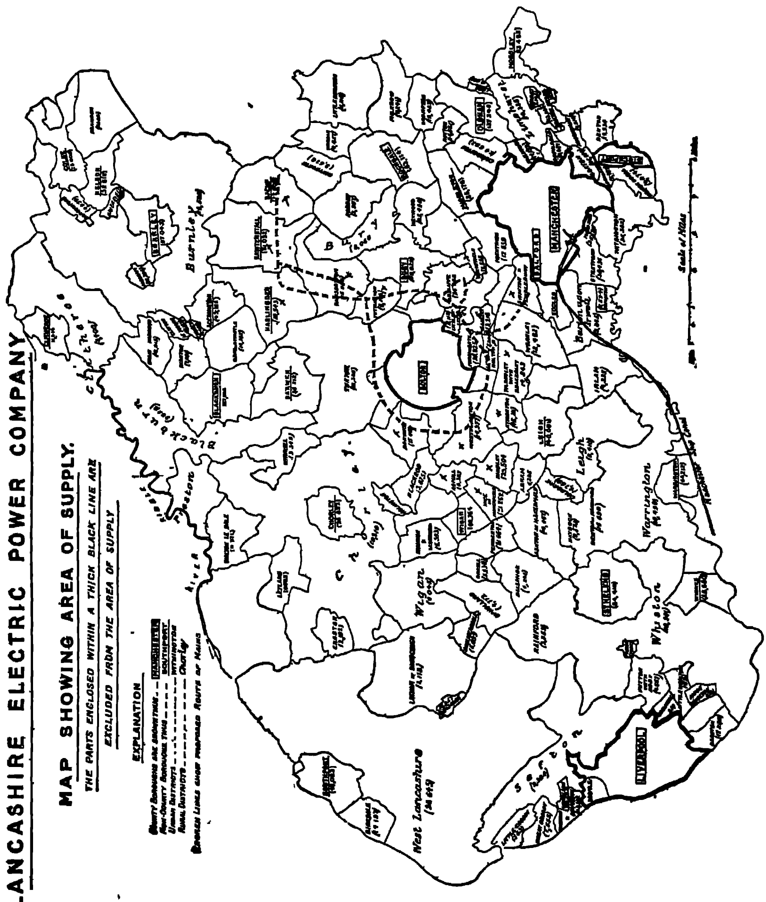


FIG. 1.

tories about 10,000. Iron foundaries 201. Fig. 2 shows the area of supply of the Yorkshire Power Company and boundaries of the local authority districts within the area, position of coal mines and location of generating stations.

Practically every class of manufacture is carried on in these districts. The load factor varies from 10 to 12 per cent in small lighting plants to 40 per cent in some mines and mills. The average load

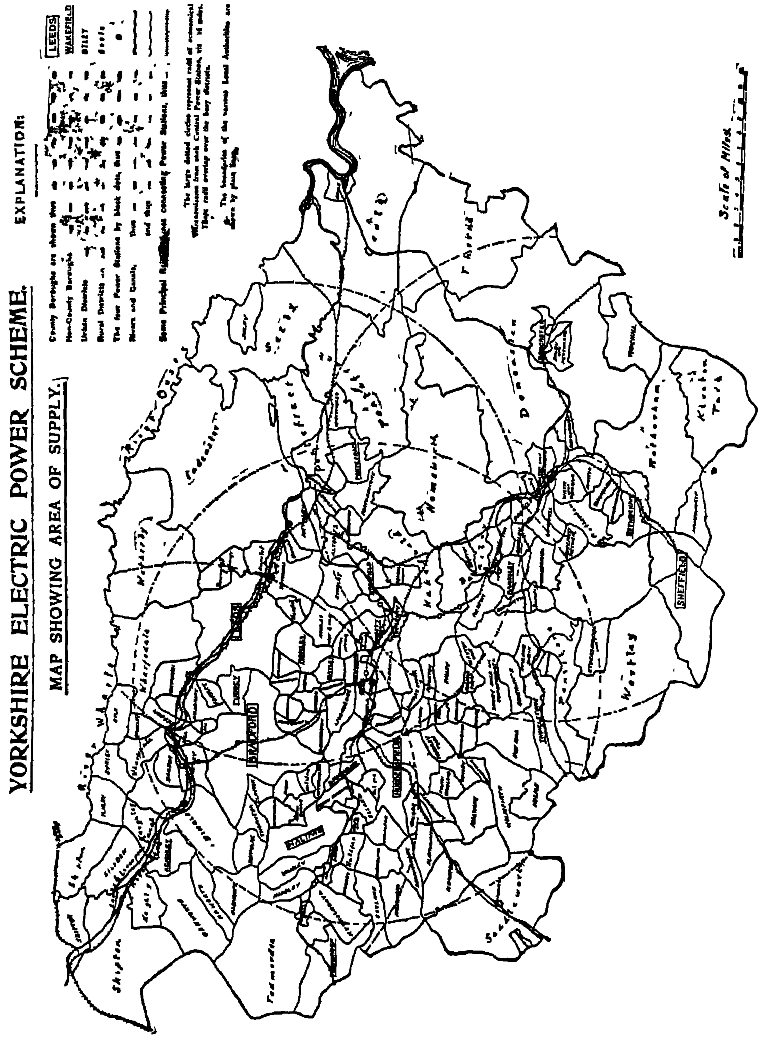


FIG. 2.

factor is computed to be 25 per cent. In making up the preliminary estimates it was necessary to investigate the conditions generally as to the cost of power to the different classes of customers. For this

purpose the consumers are classified according to the amount of power used and the extent to which they use the power, in other words, according to the maximum demand and load factor of their plant. The users of power range from 10 to 2000 hp and load factors from 5 to 50 per cent, and the costs, including capital charges, range from one-third of a penny per hp-hour to 2d. per hp-hour according to size and user. The bulk of the users, however, are factories running 56 hours per week, with a fairly steady load whilst the plant is running, and further it is not anticipated that the average user will exceed 100 kw for some considerable time. It is also estimated that the average of the consumers' load factors will be about 25 per cent. Under these conditions the following is a table of prices which consumers in these districts would pay after allowing a suitable margin as an inducement to take a supply from the Power Company: The curve corresponding to this table is shown in Fig. 5.

Hours per quarter at maximum demand.	Load factor, percentage.	Price per unit, pence.
100	4.57	5.6
120	5.48	4.6
140	6.4	4.0
160	7.3	3.5
180	8.2	3.2
200	9.14	2.9
250	11.4	2.4
300	13.7	2.00
350	15.97	1.75
400	18.25	1.6
500	22.8	1.3
600	27.4	1.15
700	32.0	1.0
800	36.5	.94
1,000	45.7	.8
1,200	54.8	.75
1;400	64.0	.65

The proposition resolves itself broadly as to how to design a plant which will generate and transmit power throughout a large area at prices which will compete with the power user's plant. Other conditions equal, the commercial advantages of a general power installation are due to the increased size of the power station; against

this must be charged the greater cost of conductors, transformers and energy loss therein. In the normal case the largest power consumer can be but a small fraction, say a twentieth or a thirtieth, of the central power installation with advantage to both parties, which is a principle essential to the permanent success of such undertakings. In the Lancashire and Yorkshire districts, however, there is the general condition that condensing water is not available to the ordinary power user, whereas central power stations can be located with proper condensing facilities, thus materially increasing the advantages of the central power installations.

Having ascertained generally the conditions obtaining in these districts and the conditions to be fulfilled by the Power Company in order to comply with the requirements of the users in supplying power to them to their advantage, and at the same time to supply at a profit to the Power Company, the next step is so to design the installation as a whole as not to exceed the limit of capital expenditure fixed by the relative cost of capital and production. The importance of capital may be realized from the fact that a power user is often so placed that he can equip his factory with a steam plant for about £12 a horse power, including condensing plant and buildings, whereas the majority of Supply Undertakings in England have spent between £80 and £100 per kilowatt capacity at the consumers' premises.

Having regard to the conditions obtaining in the Yorkshire and Lancashire districts, the total inclusive capital expenditure should not exceed the following amounts:

Capacity KW.	Capital.	Capital per KW.
5,000	293,000	58.6
10,000	519,967	51.9
20,000	974,700	47.7
30,000	1,437,000	47.9
40,000	1,880,000	47.0
50,000	2,333,000	46.6
60,000	2,787,000	46.4

Another important point to determine in such extensive districts is the limit in size of the generating station beyond which it does not pay to add to it, and as a consequence when it is advisable to build other generating stations. In the particular cases under discussion this limit is from 50,000 to 60,000 kilowatts. The areas of the two districts under notice are 1,200 and 1,800 square miles, and four

sites have been scheduled in each area in positions which are fairly symmetrical, so that the furthest point of transmission is about ten miles, giving from 300 to 450 square miles as an area of supply from each station.

The next step is to determine the voltage of transmission and other constants. The periodicity adopted is 50 cycles per second recommended by the British Standard Committee. The pressure adopted for the generators and generally for transmission is 10,000 volts, and the system three-phase. Consumers will be supplied with power in the form of three-phase currents at 10,000 volts or else at 400 volts, or in the form of direct current at 500 volts.

In the case of both the Yorkshire and the Lancashire power plants it has been decided to put down as a trial plant 6,000 kilowatts in four units of 1,500 kilowatts each. The arrangement of this plant is shown in plan on Fig. 3 accompanying this paper, and in elevation on Fig. 4. The general arrangement is the same in both cases, but the particular drawings submitted were prepared in connection with the Lancashire Power Company; generally however, the same remarks apply to both.

The plant is arranged in two main groups of 3000 kw each, each group being self contained and consisting of three boilers with a chimney, two turbine sets each provided with a separate condenser, with air and circulating pumps and suction pipe. The arrangement of plant has been adopted in order to facilitate extensions and to provide that each unit of plant bears its own proportionate cost, and that no capital is expended on account of future requirements. The unit of plant as stated is 3000 kilowatts, but in the first instalment of plant it has been necessary to subdivide this power in so far as it relates to the turbine generators and their auxiliaries, into two units of 1500 kw each, thus providing for an output of 4500 kilowatts with one unit to spare. In the first extension of plant the size of generator unit will be increased to 3000 kw.

The boilers are arranged with the line of firing floor at right angles to the line of engine house. The piping belonging to each group is interconnected. The boiler house is provided with overhead bunkers supplied by an automatic railway. This station is so located that there is a difference of level between the railway and the ground level of 70 feet.

A railway siding is constructed running parallel to the line of Power Station with a discharging hopper opposite the coal bunkers,

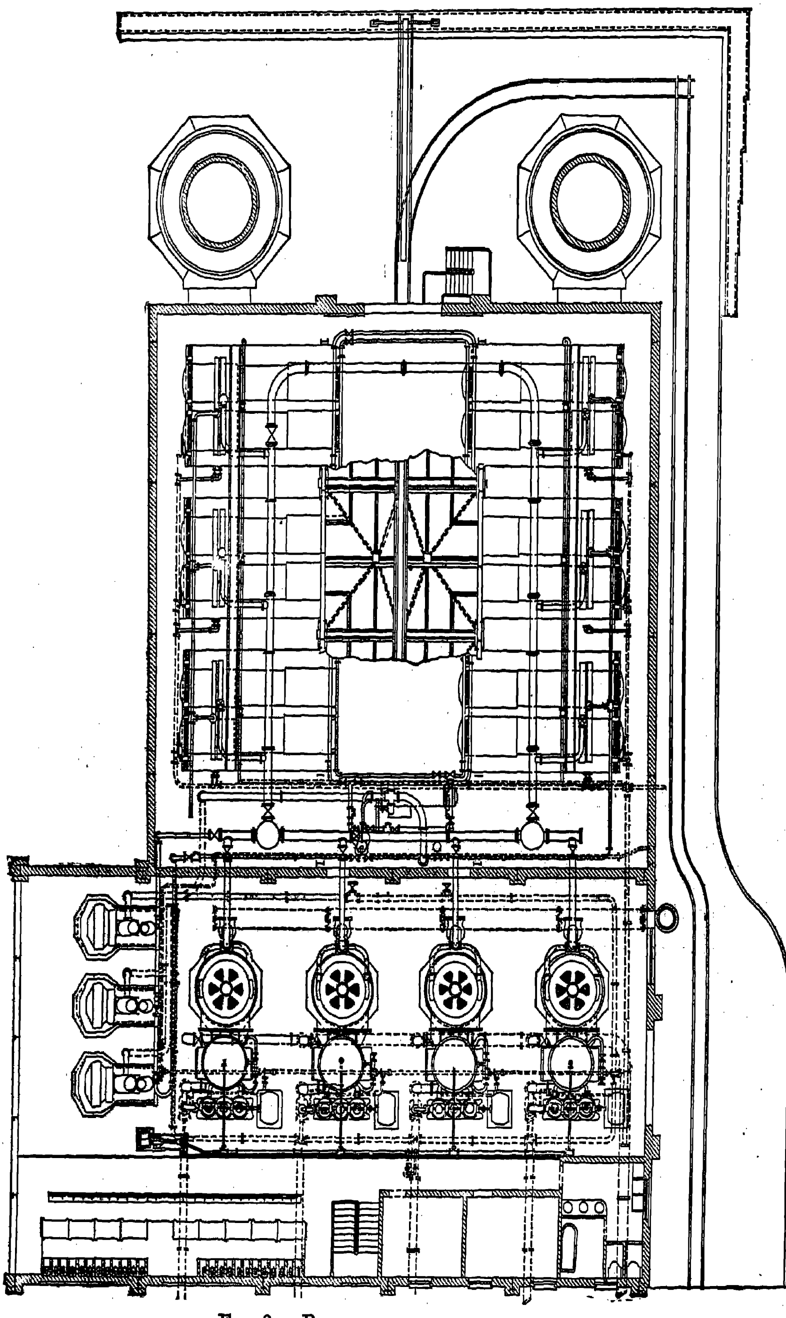


FIG. 3.—PLAN OF GENERATING STATION.

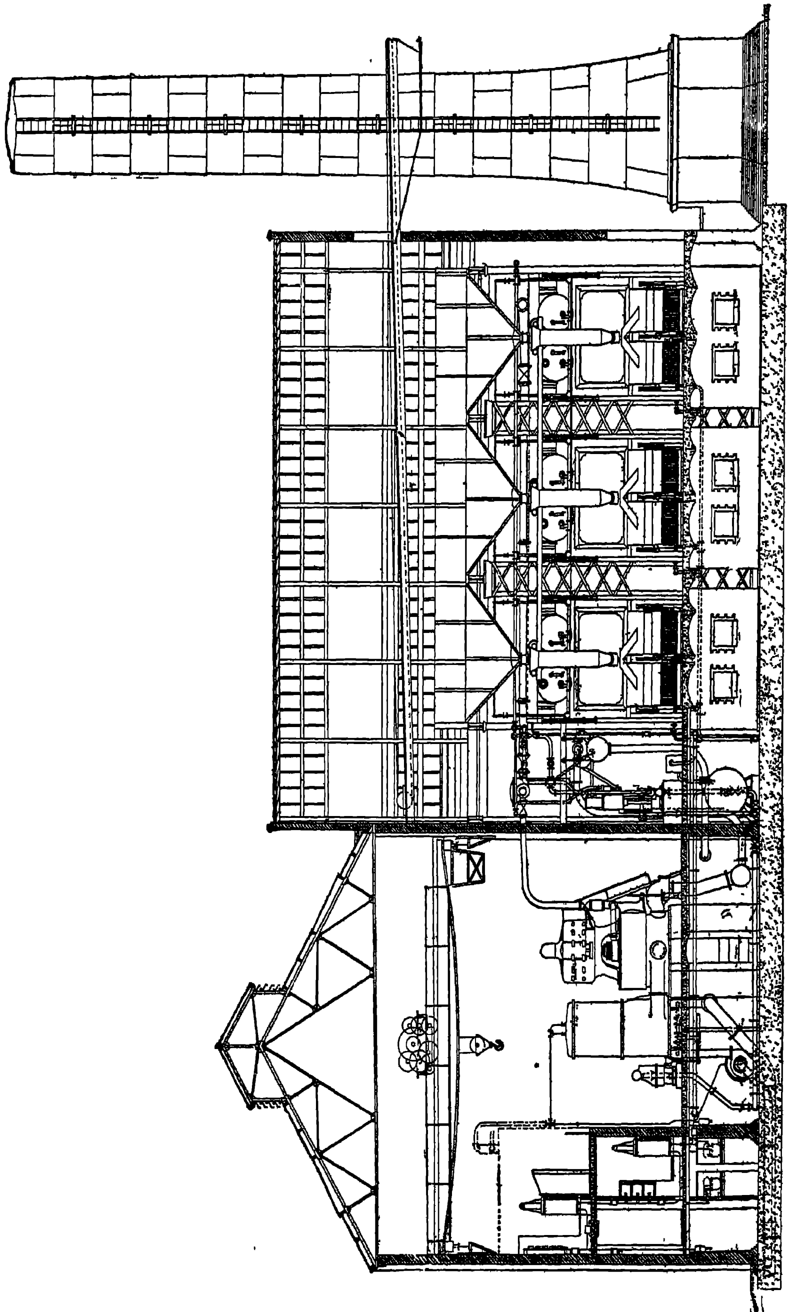


FIG. 4.—ELEVATION OF GENERATING STATION.

placed between two groups of boilers. An automatic railway is provided connecting the discharging hopper to the bunkers over the boiler room; the hopper discharges into a truck which travels by gravity to any position over the bunkers and discharges itself automatically into any of the bunkers, as may be arranged.

The boilers are of the Babcock & Wilcox water tube type, with a heating surface of 5730 square feet and a grate area of 100 square feet, fitted with superheaters having a heating surface of 510 square feet. Each boiler is rated to evaporate 20,000 lbs. of steam per hour under a pressure of 160 lbs. per square inch. Each boiler is fitted with two chain-grate stokers, each having a grate area of 50 square feet. The stokers are fed from overhead bunkers by means of automatic measuring shoots.

The condensing plant consists of surface condensers, one for each steam turbine, with vertical tubes having a total area of 4500 square feet; a motor driven air pump of the Edwards three-throw type, $15'' \times 8'' \times 165$ r.p.m.; and a motor driven circulating pump for driving 160,000 gallons of water per hour through the condenser. In connection with the condensing plant an air pump is connected to the circulating pipes and condensers for the purpose of keeping the circulating system free of air.

The exciter and auxiliary plant consists of three generators, each of 150 kw output at 220 volts. These generators are driven by reciprocating engines of the enclosed type. The exhaust steam from these is passed through a feed water heater. The arrangement of bus-bars, connection and main switches can readily be followed in Fig. 4, and consists of two sets of bus-bars interconnected by a switch; two generators and five feeders are connected to each set of bus-bars by means of switches. All the switches are of the oil-break type and operated by motor.

The buildings are substantially constructed and consist of a steel framework filled in with brick, and two steel chimneys, each chimney being 10 feet in diameter and 150 feet high.

The cost of foundations, buildings, chimneys and other works on the site, is £16,500, equivalent to £2.15.0 per kw of plant; and the cost of the plant is £96,000 or £16 per kilowatt, making a total of £18.75 per kilowatt for plant and buildings.

As regards expenditure upon transmission and distribution, it is found, as the result of negotiations with consumers, that the bulk of the supply will be in the form of three-phase; that a direct-current supply is to be the exception rather than the rule, and that

its use will practically be confined to tramway supply. In consequence it is anticipated that the expenditure upon this system will be less than the estimate, as the original estimate provided for a large proportion of direct-current supply.

Reviewing the situation as a whole, there is every probability of the whole plant and works being completed for about £45 per kilowatt.

On the basis of an average load factor of consumers of 25 per cent it is estimated that the working expenses, including operating expenses, maintenance and repairs, rents, rates, taxes and management, will not exceed 0.65 pence per unit sold, the particulars of cost being as follows:—

Operating Expenses.

Item.	Cost, pence, per kw-hour.
Generating Station:	
Coal	0.221
Oil, waste water, stores and sundries	0.042
Salaries and wages	0.115
Substations:	
Wages and supplies	0.064
Maintenance and Repairs:	
Wages and supplies	0.0895
Rents, Rates, Taxes	0.039
Management and General	0.0795
Total	0.65

Figure 5, Curve I shows how the cost varies with the load factor, and Curve II shows the gradation of prices with load factor. Referring to the scale of prices obtainable, it will be seen that on the basis of an average user of 100 kw and 25 per cent load factor, the price obtainable is 1¼d. per unit, leaving a profit of 0.6 pence per unit sold. The profit on each kilowatt of user, assuming a load factor of 25 per cent is therefore £5.5 per annum. The capital expenditure for all purposes, including promotion and purchase of land, may be taken at £70 per kilowatt of user.

In the foregoing I have outlined the circumstances affecting power companies in England, the limitations imposed upon them by Parliament, the prices obtainable having regard to the size and extent of user. I have then described the most economical type and ar-

rangement of plant to meet the conditions obtaining. It is, of course, recognized that the advantage which the power companies have over individual power users is small at first, and that the margin of profit will grow with the increase of business.

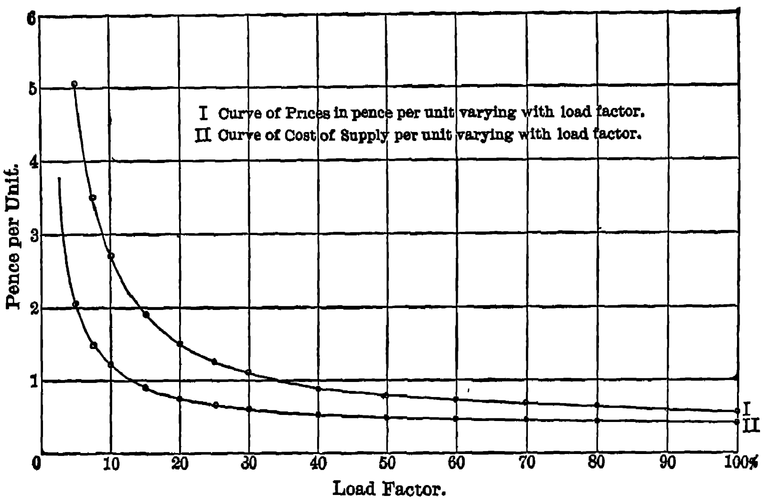


FIG. 5.—CURVE OF PRICE FROM CONSUMERS AVERAGING 100 KW, AND OF COST OF SUPPLY FROM 6000-KW STATION.

The conclusion to be drawn from this paper is that these undertakings, if carried out on the basis outlined, can be made remunerative from the commencement, and that beginning with a 6,000-kw plant, there is sufficient margin to show a satisfactory return on the capital employed.

CHAIRMAN LIEB: In closing this final session of Section E, I wish to thank the gentlemen for their assiduous attendance at the meetings, and for the interest manifested.

On motion of Mr. Dick a vote of thanks to Chairman Lieb for the efficient manner in which he presided over the Section, was unanimously accorded.

The Section then adjourned *sine die.*